STEEL

AND ITS TREATMENT

E. F. HOUGHTON & Co.

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AND ITS TREATMENT

BY THE

METALLURGICAL STAFF

OF

E. F. HOUGHTON & CO.

———

THIRD EDITION

ILLUSTRATED

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PHILADELPHIA

E. F. HOUGHTON & CO.

1918

FOREWORD TO THIRD EDITION

THE welcome reception of our second edition of this book by the iron and steel working industries has encouraged us to greater effort in striving to make this third edition worthy of a place on every steel worker's bookshelf.

From the first chapter the book has been almost entirely rewritten, numerous micro-photographs and other illustrations have been added, and the steel specifications of the Society of Automotive Engineers have been corrected to date of going to press.

Grateful acknowledgment is due Mr. L. A. Cummings, metallurgist of the New Departure Manufacturing Co., Bristol, Conn., for painstaking assistance in editorial work; to Mr. Howard J. Stagg, Jr., metallurgist of the Halcomb Steel Co., Syracuse, N. Y., for several of the micro-photographs reproduced herein; to Mr. Frank N. Sim, advertising manager of the Timken-Detroit Axle Co., Detroit, Mich., for photographs of the Timken Roller Bearing Co. plant at Canton, Ohio; to Mr. A. L. Goddard, Superintendent of Shops, University of Wisconsin, Madison, Wis., for many helpful suggestions which were adopted; to the Society of Automotive Engineers for permission to reproduce the steel specifications; to the

editors of *Machinery,* who kindly consented to the use
of illustrations which originally appeared in that publ-
lication, and to the many others who have promptly and
liberally done their bit to aid us in our efforts.

FOREWORD TO SECOND EDITION

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FOR over forty years E. F. Houghton & Co. have been engaged in the manufacture of products used in the heat treatment of steel.

During that period they have conducted a laboratory of research that they might best comprehend the requirements of the steel industries and thus produce the best products.

This research work has been carried on by the metallurgical force of the Company, and for many years consisted mostly in absorbing the individual experience of each works where for the most part nothing more than rule of thumb methods was applied.

During the last fifteen years with the rapid development in the heat treatment of steel, owing to the increased demand for high-service machine parts, a more careful and scientific study of the heat treatment of steel has been possible, and this little work is nothing more or less than the collection of such data as has been obtained from time to time by our metallurgical force plus the correction of palpable errors, the reconciling of seeming inconsistencies and the deduction of a code of principles.

The object of this little work is to aid the reader in a clearer understanding of the wonderful metal—steel—in

the hope that it will help improve the quality of output and the economy of operation.

With this accomplished, all we aimed at, namely success, will have been attained.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER I

COMPOSITION OF STEEL

Steel is not a simple substance like pure iron, gold or copper, but a complex artificial product. It is composed of groupings of many constituents which enter into its makeup as granite rock is built up of the minerals quartz, mica and feldspar. These constituents, as they may be called, are only visible with the aid of the microscope.

Upon etching a highly polished piece of steel, this granitic structure is made apparent through the action of the etching medium (acid or other corrosive or abrasive material) which affects the constituents variously, causing each to assume a structure peculiar to itself.

Steel lies between wrought iron or nearly carbonless iron on one hand, and cast or high carbon iron on the other, and is practically free from slag. It differs from both in that it is susceptible to more marked physical and structural modifications than either upon the application or abstraction of heat.

Iron containing less than .03 per cent. carbon is generally called wrought or ingot iron, and contains considerable slag (Fig. 1); more than .03 per cent. and less than 1.80 per cent. carbon is called steel; while with a content of 1.80 per cent. carbon or over it is considered cast iron.

Steel is composed of pure iron or ferrite and iron carbide (Fe_3C, containing 6.6 per cent. carbon, 93.4 per cent. iron), together with certain impurities in solid solution. The Ferrite of commercial grades of iron and steel is not pure iron, but rather a solid solution of iron holding small amounts of silicon, phosphorus and other impurities.

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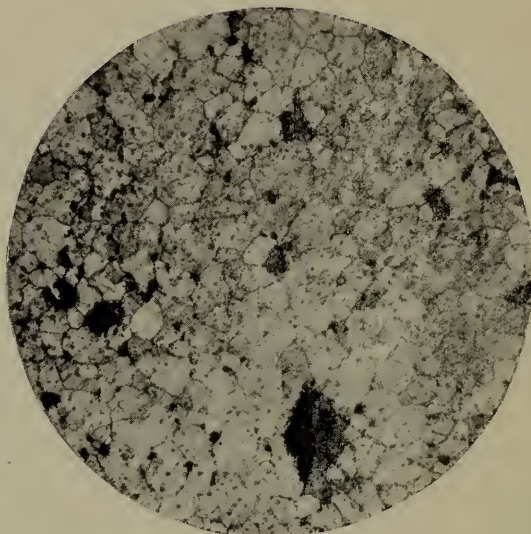
Fig. 1.
Wrought Iron. White Areas, Ferrite. Dark Patches, Slag.
Magnification, 75 Diameters.
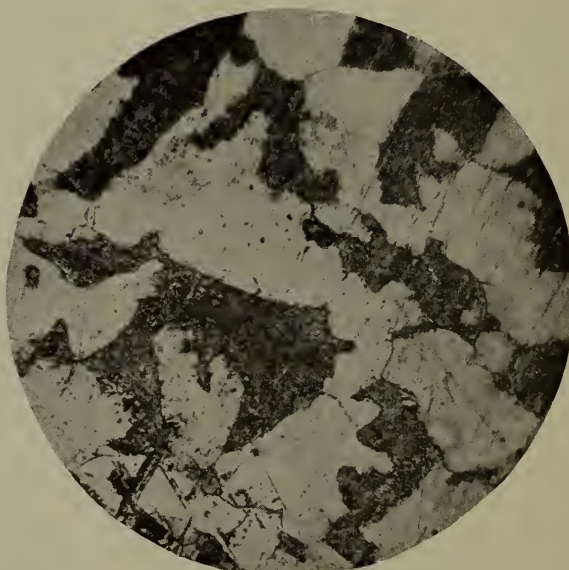
Fig. 2.
Steel.   White Areas, Ferrite.   Dark Areas, Pearlite.
Magnification, 100 Diameters.

A certain fixed amount of carbide will dissolve in iron
and when that fixed amount is exceeded, there will be a
precipitate of free carbide called "Cementite." The point
of complete saturation of Ferrite with Cementite is reached
at .85 to .90 per cent. carbon; in plain carbon steels, and
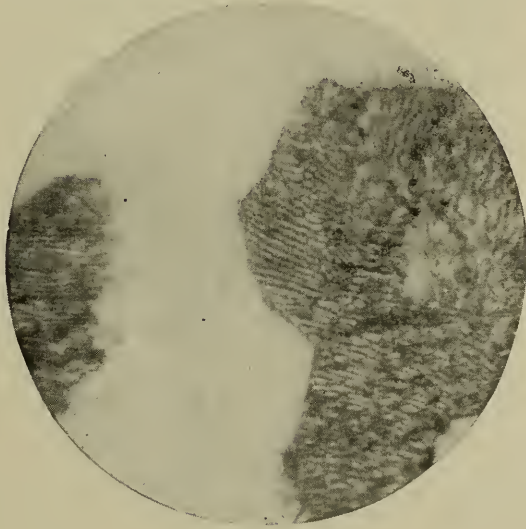
Fig. 3.
Steel. White Areas, Ferrite. Dark Areas, Pearlite.
Magnification, 1000 Diameters.

in the soft and annealed condition the microscopic struc-
ture shows neither Ferrite nor Cementite but a mechan-
ical mixture called "Eutectoid" or "Pearlite." (Fig. 5.)

The behavior of iron upon the addition of carbon is
about as follows:

At first we have pure iron or Ferrite, then as we add
a little carbon which with the Ferrite forms Cementite,
the result is not free Cementite but a mixture of Pearlite
(which is in turn a mechanical mixture of Cementite and
Ferrite, but always in a certain fixed proportion) and
Ferrite (Figs. 2, 3 and 4.) As the carbon increases
the amount of Pearlite increases until all the Ferrite has
been used up in its formation, and the steel consists en-
tirely of Pearlite (Fig. 5). This occurs at .85 to .95 per
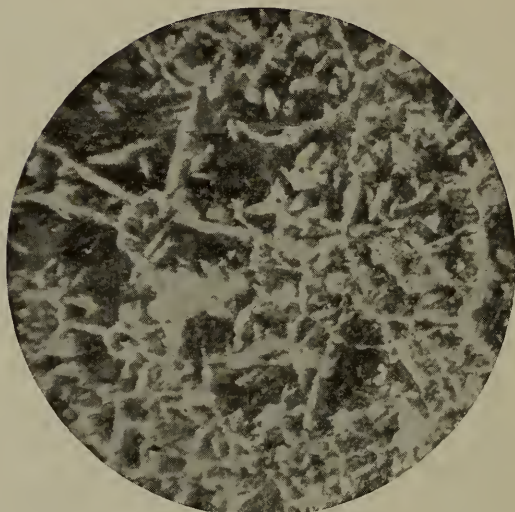
Fig. 4.
White Areas, Ferrite.   Dark Areas, Pearlite.
Magnification, 150 Diameters.
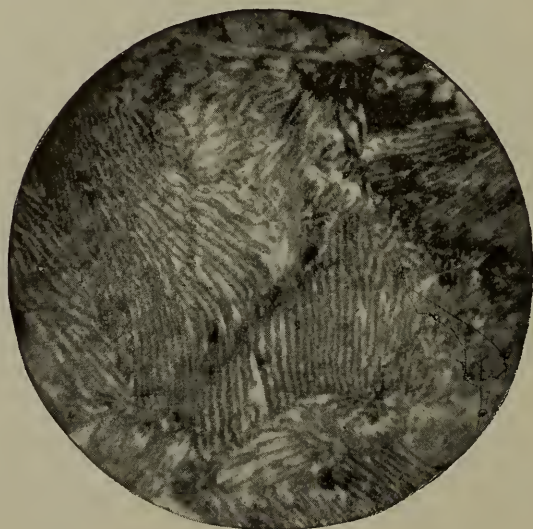
Fig. 5.
Pearlite or "Eutectoid."   Magnification, 1000 Diameters.

cent. carbon, and when the carbon content exceeds this amount, we begin to get excess Cementite (Fig. 6) ; the formation of excess Cementite up to 6.6 per cent. carbon giving a structure composed entirely of Cementite, if such an alloy was commercially available, as cast iron or steel.
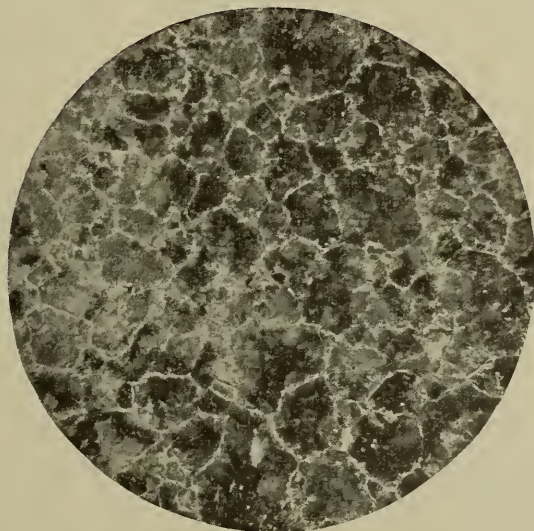
FIG. 6.
Dark Areas, Pearlite. White Lines, Excess Cementite.

The carbon content of a steel may be estimated by the relative percentage of each constituent present as shown under the microscope, as .90 carbon steel will show all Pearlite ; .45 carbon steel half Ferrite and half Pearlite, and 1.50 carbon steel 90 per cent. Pearlite, 10 per cent. Cementite.

Like most substances, these combinations of constituents are decomposed by the action of heat, new ones being formed. Water at 60 degrees Fahr. is a liquid. It is likewise a liquid at 211 degrees Fahr., but at 212 degrees Fahr. it becomes vapor or steam. So the elements Ferrite and Pearlite in hypoeutectoid steel or Pearlite and Cementite in hypereutectoid steels remain at such up to a temperature of 700° C. (1292° Fahr.) to 845° C. (1553°

Fahr.), depending upon the quantity of each present, when they decompose through several transitional stages, forming a new constituent known as "Austenite," as shown in Fig. 7, or Austenite and Cementite in case of hypereutectoid steels.
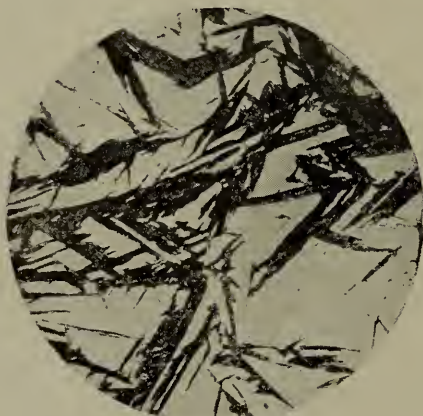
Fig. 7.
Austenite and Martensite (Osmond).
Reduced one-half from original of 1000 Diameters.

Now this Austentite differs materially in its properties from either Ferrite or Pearlite, in that, if it or more usually one of its transitional forms, Martensite, be preserved by quenching the steel, it will be found hard and brittle, while Ferrite and Pearlite are soft and tough. Again Ferrite and Pearlite attract the magnet under all conditions, while the new constituent, Austenite, in its hot condition does not; but in its cold condition it acts the same as Ferrite and Pearlite.

On account of the close relation existing between the treatment and structure of steel, and the structure and physical properties, one realizes the importance of gaining a knowledge of what is called the critical points in steel, in order to lay the foundation for its heat treatment.

CHAPTER II

THERMAL CRITICAL POINTS OF STEEL

If one should watch the slow heating of a piece of steel in a furnace, it would be noted that the temperature of the steel gradually increases with the increasing heat of the furnace until a temperature is reached when the steel may become slightly darker and cooler than the furnace. As the heating is continued the piece will again assume the temperature of the furnace.

In the rising heat the darkening of the piece of steel is due to the absorption of heat to convert Ferrite and Pearlite into Austenite.

Now if the furnace be permitted to cool slowly, during some point in the process the steel may become brighter or visibly hotter than the furnace, after which it assumes its normal rate of cooling which continues on down to atmospheric temperatures.

Such a rise in temperature in slow cooling indicates a giving off of heat during the conversion of the Austenite back to Ferrite and Pearlite.

Fig. 8, taken from *Machinery*, July, 1912, shows clearly this loss and gain of heat at the points Ac and Ar.

A transformation of the constituents composing the steel accompanies these thermal changes—as, for example, on heating, the decomposition of Ferrite and Pearlite to form Austenite, as mentioned above, or vice versa, the decomposition of the Austenite into its constituents, Ferrite and Pearlite, as the case may be, during slow cooling.

The temperatures or points where these changes take place during the heating and cooling are called the critical points of steel. To distinguish between these two
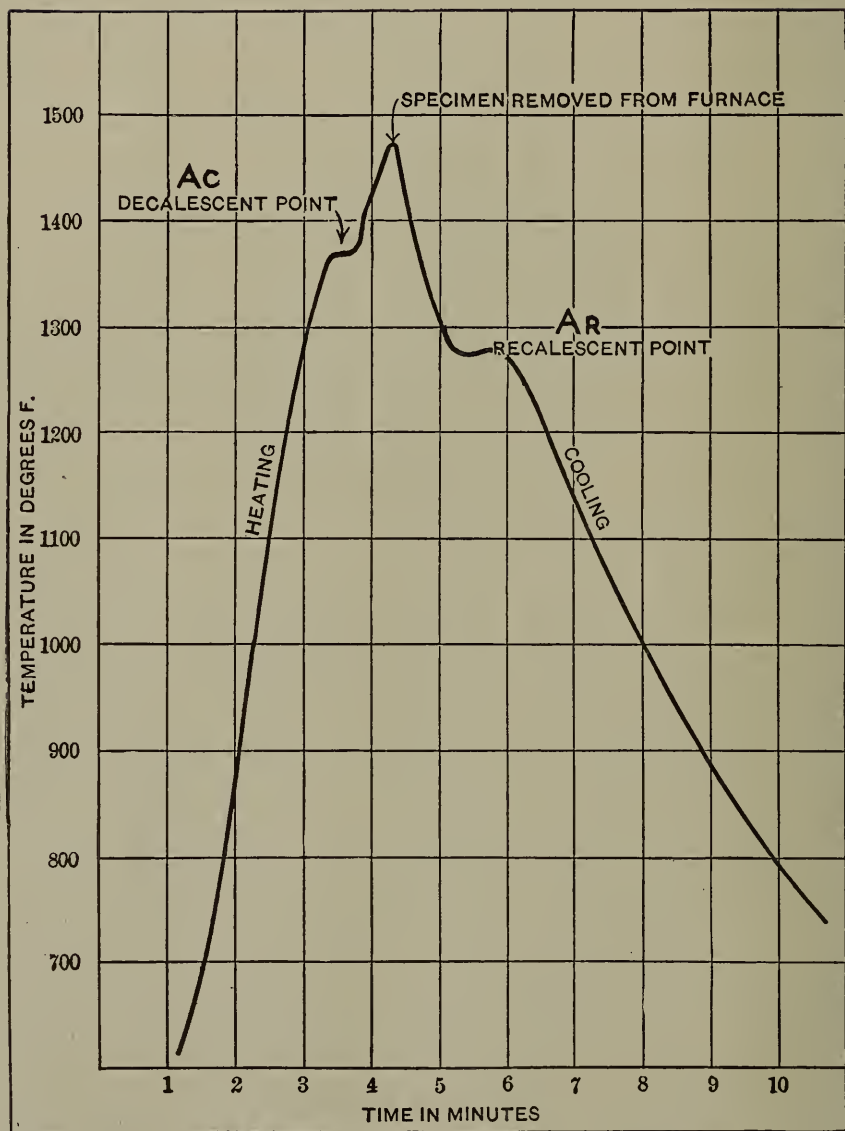
FIG. 8.

points, or ranges as is actually the case, those occurring on the heating are termed "Decalescence" and those on the cooling "Recalescence" points.

These terms are usually noted by the symbols Ac for Decalescence and Ar for Recalescence. The sub numerals attached as in Chart, Fig 9, refer to other critical temperatures at which other structural changes take place under similar conditions.

When the various critical points occurring in steel are considered collectively, the range of temperature that they cover is called the critical range. The critical range may include one, two or three points. The meaning of the expressions "Critical Range on Heating" and "Critical Range on Cooling" is obvious.

The carbon percentage influences the location of the thermal points as shown in Roberts-Austen Chart, Fig. 9.

These ranges have a value which is of great importance in practical work.

Without a lengthy discussion of the theoretical points of the Roberts-Austen Chart, Fig. 9, we will consider steels under heat conditions of various carbon contents. Take for instance, a steel containing less than .37 per cent. carbon, as it passes through Ac1, the initial Pearlite begins to change to Austenite, the solid solution, and then begins to absorb the free Ferrite until at Ac3 the original steel is entirely composed of Austenite. On slow cooling the reverse is true. The conversion temperatures being lowered, as shown at Ar3, Ar2 and Ar1. However, when quenching at a temperature corresponding to A, above Ac3, we do not retain Austenite but Martensite. It is impossible to obtain Austenite in commercial work, as the quenching is not sufficiently rapid to retain this condition. Martensite (Figs. 10a and 10b) is harder and somewhat more brittle than Austenite. If, however, we quench at a point corresponding to temperature C, we retain Ferrite and Pearlite or Sorbite.

Considering, next, a steel of carbon content, between .37 and eutectoid, we have, on heating, only two critical tem-
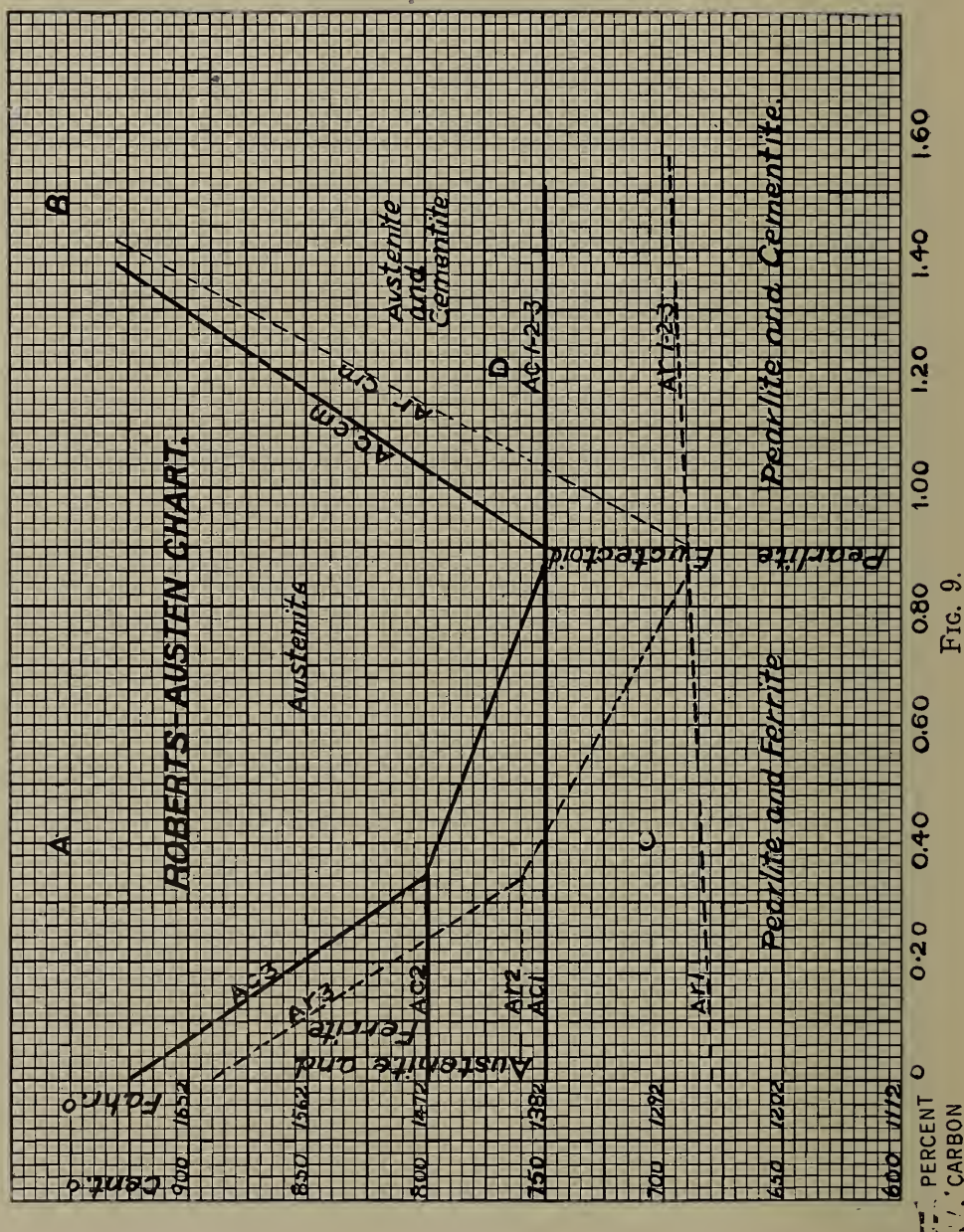
FIG. 9.
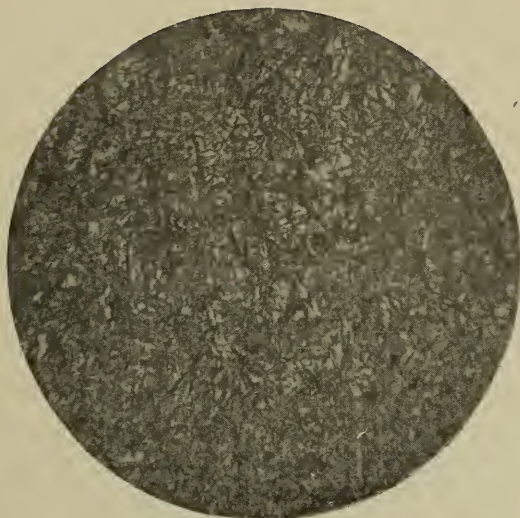
FIG. 10A.
Martensite.   Magnification, 375 Diameters.
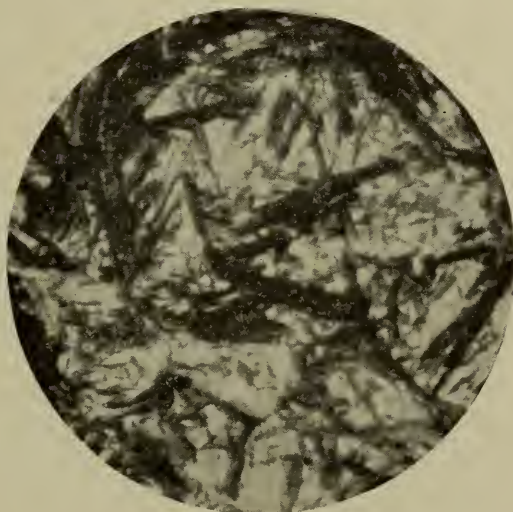
FIG. 10B.
Martensite.   Magnification, 1000 Diameters.

peratures, Ac1 and Ac32. In this case the initial Pearlite is greater than Ferrite and the transformation to Austenite and the absorption of Ferrite are more rapid.

For a Eutectoid Steel, .85 to .90 per cent. Carbon, all the critical temperatures on heating are merged into a common Ac321. There being no free Ferrite, but only Pearlite present, the transformation takes place rapidly and at one time.

Hypereutectoid Steel consists of Pearlite and Free Cementite. On heating through Ac321 the Pearlite is changed to Austenite. If we heat past the upper critical point Accm the Austenite dissolves the free Cementite and the steel becomes entirely Austenitic. It will not be necessary, in ordinary commercial treatments, to consider the Accm critical temperature. If steel is quenched from a temperature corresponding to B, in Fig. 9, in ice water, the Austenite can then be retained. If steel is quenched at a temperature corresponding to D, in the chart, the structure retained will be Cementite and Martensite.

The decalescent and corresponding recalescent points do not occur at exactly the same temperature, the decalescent points generally occurring some 25° C. (77° Fahr.) to 50° C. (122° Fahr.) higher than the recalescent. For instance, in Fig. 8, you will note the point Ac is shown at 750° C. (1382° Fahr.), while the corresponding Ar point is 690° C. (1274° Fahr.).

It does not follow, however, that these two points are not the opposite phases of the same phenomena. The fact that the critical point on cooling lags behind the point on heating, and vice-versa, is evidently a case of hysteresis, so often observed in physical phenomena, implying a resistance of certain bodies to undergo a transformation, when theoretically the transformation is due.

The slower the process of heating and cooling, the nearer will the two points approach each other, so that with infinitely slow cooling and heating they would undoubtedly occur at exactly the same temperature.

CHAPTER III

CLASSIFICATION OF STEEL

Steels are commonly divided in two classes—straight carbon steels and special steels, or alloy steel. The former differ from the latter in that they are made up almost entirely of iron combined with more or less carbon and containing small amounts of such elements as manganese, sulphur, phosphorus, silicon, while the special steels result from alloying the above with nickel, chromium and vanadium and other elements.

Straight Carbon Steels

Steels are generally graded according to the amount of carbon they contain. The following terms are those most commonly used:

Very low carbon steel, very mild or extra mild steel;

Very soft, dead soft steel—carbon not over .10 per cent.;

Low carbon steel, mild steel, soft steel—carbon not over .25 per cent.;

Medium carbon steel, high carbon machinery steel—carbon .26 to .60 per cent.

High carbon steel, tool steel—carbon over .60 per cent.;

Extra high carbon steel, high carbon tool steel—carbon over 1.25 per cent.

This classification is somewhat arbitrary, as there are no sharp lines in the carbon percentages of separation universally recognized between the various grades.

Steel containing .85 to .90 per cent. carbon is also known as "Eutectoid" steel, that containing less than

.85 per cent. carbon as "hypoeutectoid" steel, and more than .90 per cent. carbon metal as "hypereutectoid" steel.

Low Carbon Steels

If one should study the rate of cooling of a sample of steel containing some .10 per cent. carbon, from a high temperature, three thermal retardations would be detected: Ar_3, at about 850° C. (1562° Fahr.); Ar_2 near 760° C. (1400° Fahr.), and Ar_1 about 700° C. (1292° Fahr.). Of these three critical points the Ar_3 would be the most marked, while Ar_2 and Ar_1 would be faint. On heating, corresponding retardations will occur, due to spontaneous absorption of heat, the critical points being designated as Ac_3, Ac_2 and Ac_1. Of these, Ac_3 and Ac_1 will occur at temperatures some 25° C. or more higher than Ar_3 and Ar_1, while Ac_2 will be nearly the same as Ar_2—that is, about 760° C. (1400° Fahr.).

The point A_2 is generally less marked than the points A_3 and A_1, and unlike A_3, its position is little affected by the carbon content; and unlike A_3 and A_1, the point on heating Ac_2 occurs at nearly the same temperature as the point on cooling Ar_2.

Thermal Critical Points of a Medium Carbon Steel

The cooling of a steel containing about .45 per cent. carbon reveals the existence of two critical points: One, evidently the point of recalescence, Ar_1, at the usual temperature, 700° C. (1292° Fahr.), and one upper point around 740° C. (1364° Fahr.). It is generally assumed that the two upper points have united to form a single one, and is designated accordingly by $Ar_{3,2}$. Increasing the carbon content decreased the interval of temperature between the two upper points, until finally for a certain carbon content the points meet to form the double point

Ar3, 2. This appears to occur in commercial steels at about .30 per cent. carbon.

High Carbon Steels

Eutectoid steel (.85 to .90 per cent. carbon) shows a single very marked critical point on cooling at 700° C.
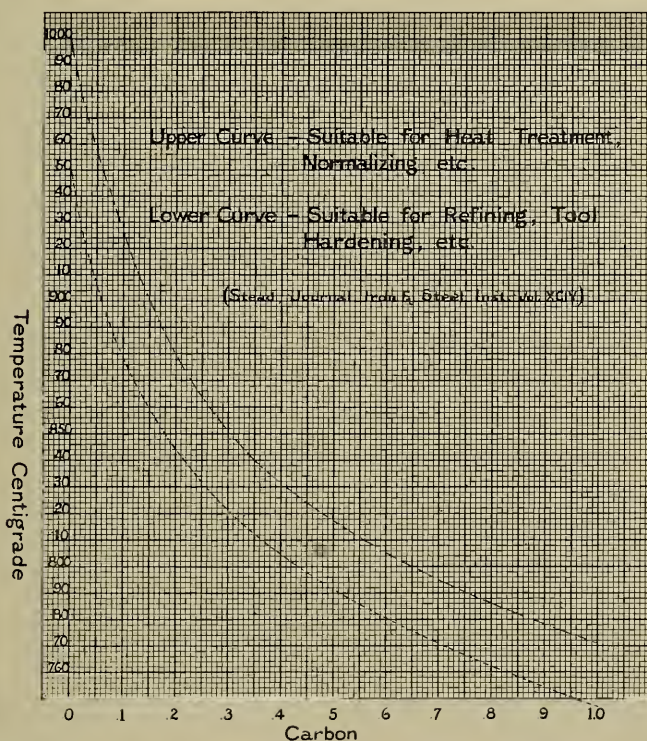
Fig. 11.

Normalizing or Heat Treating and Hardening Temperatures for Plain Carbon Steels.

(1292° Fahr.) which is designated by the symbol Ar321, the three points having merged. In hypereutectoid steels, there is an upper critical point Acm, which corresponds to the point where the excess Cementite is absorbed or rejected by the Austenite (which has transformed from

the Pearlite) as the case may be. This point varies from 700° C. (1292° Fahr.) to 1000° C. (1832° Fahr.) as the carbon content ranges from .85 to 2.00 per cent.

In order to put rolled or forged steel into the best and most uniform condition for subsequent treatments (hardening and tempering) it is often normalized. Normalizing consists of heating steel to certain definite temperatures well above all critical points and cooling at the proper rate to below redness. Properties of the steels of course will vary according to temperatures and rate of cooling. High carbon steels must be treated above the Ac.cm range to break up net work and large crystals of Cementite. The accompanying curves show suitable normalizing or heat treating temperatures and the hardening temperatures for plain carbon steels.

CHAPTER IV

EFFECT OF THE ELEMENTS IN STEEL

The elements that combine to make steel, their relation to one another, the effect when the percentages of two or more are changed, which add or take away certain physical properties of the steel, and their action upon heating and cooling, offer a field that cannot be covered in this treatise. However, it may be well to give the general characteristics of these elements as they manifest themselves in the heat treatment and establish a relation between the chemical analysis of steel and its effect on the final product.

CARBON

The general influence of carbon in steel is to give greater tenacity. It also renders the steel susceptible to heat treatment. The tensile strength is increased about three to four tons per square inch for each additional .10 per cent. carbon, while the ductility is decreased about 5 per cent. for each additional .10 per cent. carbon. Steel, with .20 per cent. carbon, begins to show appreciable hardening when cooled quickly, but does not show evidence of brittleness in the normal state until the carbon has reached approximately .70 per cent. For the most part, the tables and treatments, together with the physical properties that are mentioned later on, are the best indications of the properties of carbon and its relation to steel and the other elements.

MANGANESE

Manganese is an element always found in steels, but its true properties and effects were not known until about

3

twenty years ago, when they were discovered by R. A. Hadfield, a metallurgist and steelmaker of Sheffield, England.

When more than 2 per cent. and less than 6 per cent. of manganese is added, with the carbon less than 0.5 per cent. it makes the steel very brittle.

From 6 per cent. of manganese up this brittleness gradually disappears until 12 per cent. is reached, when the former strength returns and reaches its maximum at about 14 per cent. After this a decrease in toughness, but not in transverse strength, takes place until 20 per cent. is reached, after which a rapid decrease again occurs.

Steel with from 12 to 15 per cent. of manganese and about 1.25 per cent. of carbon is very hard and cannot be machined or drilled in the ordinary way; yet it is so tough that it can be twisted and bent into peculiar shapes without breaking.

Manganese in the form of a ferro compound containing about 80 per cent. of manganese, is added to steel at the time of tapping, so that the manganese may absorb the oxygen, which is dissolved in the bath, and transfer it to the slag as oxide of manganese. Manganese prevents the coarse crystallization which the sulphur and other impurities would otherwise induce, and steels low in phosphorus and sulphur require less manganese than those having comparatively high percentages.

The maximum temperature to which it is safe to heat steel, both in its manufacture and subsequent treatment, is raised by manganese, owing to its resisting the separation of the crystals in cooling and conferring the quality of hot ductility. This makes it one of the most valuable factors in the making of steel if the proper percentages are used.

PHOSPHORUS

The impurities, phosphorus and sulphur, have been the bane of engineers, designers and all users of steel prod-

ucts, and more time, more energy and more money have been spent to get rid of phosphorus than any other element in steel. It was formerly thought that phosphorus up to about .12 per cent. strengthened steel, but when these same steels were put into actual use they failed and the cause was nearly always traced to the phosphorus. In the rolling mill, phosphorus does not show any bad effects, as the heat under which the steel is worked seems to overcome them, but when the metal has cooled and is subjected to sudden shock or to vibrational stresses it breaks very easily. The lower the temperature and the higher the phosphorus the more brittle the steel. This had led to the term "cold shortness," being applied to the effect of phosphorus in steel.

Phosphorus reduces the ductility of steel under a gradually applied load, as shown by the reduction of area, elongation and elastic ratio when specimens are pulled in the ordinary, static strength-testing machine. But when the steel is tested in the rotary or alternating vibrational-stressing machine, as well as with a pendulum-impact machine, the decrease in ductility and toughness is shown to a much greater degree.

High phosphorus steels (over .10 per cent.) are coarse grained and may show a reasonably high static ductility and still show brittleness when shock tests are applied.

Therefore, for all steels subjected to strains, or sudden shocks, the phosphorus content should be below .045 per cent.

Sulphur

Sulphur causes steel to crack and check in rolling, forging, heat-treating or hot working, and therefore the term of "hot shortness" has been applied to its effect on steel.

Since manganese has a great affinity for sulphur these two elements, when brought together at the high temperature in the manufacture of steel, combine chemically,

forming manganese sulphide (Fig. 12), which segregates and collects between the crystals of the steel and if present in large quantities causes an injurious effect by reducing the crystalline cohesion. Red shortness is probably caused by the melting of manganese sulphide (which has a lower melting point than steel) during hot
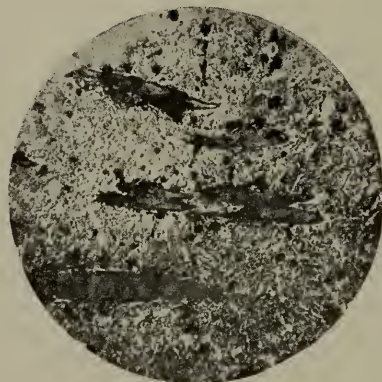
FIG. 12.
Dark Areas, Manganese Sulphide.
Reduced one-half from original Diameter of 50.

working which destroys the cohesion between the grains of the metal and produces cracks. Hence, the percentage of sulphur in steel should be extremely low. It is customary to specify steel containing less than .05 per cent. sulphur.

Phosphorous and sulphur up to .12 per cent. are often added to give machining properties, but this gives a poor quality steel.

SILICON

Silicon has a tendency to remove the gases and oxide from steel as well as the traces of dissolved oxygen. This prevents the formation of blow holes and gives the steel greater soundness and toughness. Thus it is better able to withstand wear or crushing from continual pounding.

The influence of silicon, on the results of quenching, is similar to that of carbon in many ways. It is also dependant upon the co-existing amount of carbon and

manganese.   It neutralizes the injurious tendencies of manganese.

Nickel

Nickel in steel increases its strength, ductility, toughness, resistance to abrasion and shock.   It also increases very considerably the ratio of the elastic limit to the tensile strength, and renders these steels more susceptible to heat treatment.

Steels contain from .50 per cent. to 5 per cent. of nickel, according to the desired results.

An addition of 2 per cent. nickel to a steel, when properly treated, will increase its strength to nearly double that of straight carbon steel of the same carbon content.

Nickel added to ordinary carburizing steel in comparatively small percentages obviates the brittleness of the core which is usually produced by carburizing and gives more uniform results.

These steels, when properly carburized and heat treated, give excellent service in such parts as shafts, ball and roller bearings, gears, etc.

It should be remembered, however, that the mere addition of nickel to steel does not guarantee exceptional physical properties, which can only be obtained by the most careful heat treatment.

In recent years considerable work has been done on the higher nickel steels which give a Martensitic structure on air cooling.   These experiments have been conducted on high carbon, high nickel steels, as well as low carbon, high nickel steels carburized.   The theory of this process is based on the retaining, by the presence of the high nickel content, of the Martensitic structure on slow cooling, thereby eliminating the quenching operation.   It should be remembered that the Martensitic structure of ordinary high carbon steel can only be retained by rapid cooling, such as quenching.

The critical temperatures are lowered by the addition of nickel.   In commercial steels (under 7 per cent. nickel)

for each one per cent. of nickel Ac will be lowered 15°
Fahr. (8° C.) to 20° Fahr. (11° C.), and Ar 30° Fahr.
(17° C.) to 40° Fahr. (22° C.), below the same ranges
for straight carbon steels of the same carbon content.

CHROMIUM

Chromium added to steel increases the elastic limit,
hardness, resistance to shock and alternate stresses.

It is the most active element in making steel respond
to heat treatment, giving the greatest hardening depth
obtainable with any steel.

This element decreases the tendency of crystalline
growth and imparts a very fine dense grain structure.

In the rolled or forged condition low chromium, in
combination with low carbon, has practically no effect
on the physical properties, but it affects materially the
results obtained by heat treating the same.

Extreme hardness may be obtained in chromium steels,
as the chromium intensifies the sensitiveness of the metal
to quenching and greatly reduces the liability to fracture,
which is found in carbon steels.

Chromium steel practically shows extremely fine grain
and possesses a high power of resistance to shocks. This
has made it almost universally used for armor plate.

When chromium is combined with nickel or vanadium
it makes the strongest and best wearing commercial steel,
and can be machined much more easily than when
chromium alone is used. Small gears can be made with
these alloying materials added to the steel so that if prop-
erly heat treated they will be so tough and strong as to
make it almost impossible to break out a tooth, even with
a hammer. Some of the best grades of chrome nickel or
chrome vanadium steel contain from .75 to 1.50 per cent.
of chromium. Chromium renders the steel more homo-
geneous and gives it the ability to resist shock and tor-
sional stresses. Thus, this alloy is one of the best steels
for crank shafts of internal-combustion engines or other

parts of machinery which have to withstand similar vibrational stresses.

The chrome nickel steels are difficult to forge, as it is dangerous to hammer them after the temperature has dropped below that which makes the metal a bright yellow. It must be heated repeatedly to forge pieces of any size or intricate shape.

Vanadium

Vanadium has made great strides in the past few years as an alloying element, and is used in steel castings and cast iron as well as in steel mill products.

Vanadium, when added to steel in percentages up to 2 per cent., has a marked effect upon the physical properties, particularly decreasing the susceptibility to sudden shock stresses and fatigue.

Owing to its affinity for oxygen it acts as a cleanser to the metal, thereby increasing the molecular cohesion.

Vanadium also removes nitrogen, which is very detrimental to steel, even in infinitesimal quantities.

Vanadium steel is used largely for crank shafts, connecting rods, piston rods, crank pins, gears, saws, gun barrels, springs, etc.

Impurities in Steel

Impurities in steel usually show up when casting the ingot. These impurities are in the forms of segregation of elements, blow holes, slag, etc. The top of the ingot is usually in the poorest condition. Cutting off the top, called "cropping," if sufficiently done, removes this trouble. However, in the process of pouring the molten steel into the mold the outside becomes chilled before the core; this, besides tending to trap slag, etc., exerts a pulling effect on the core, causing piping and blow holes. In the case of high carbon steels cracks are liable to develop. Due to the lower heats at which high carbon steels must be

hot worked, these cracks seldom weld up, causing trouble
all the way through the finished product.   A recently de-
veloped method of pouring the ingot, called "box pour-
ing," promises to give a sounder ingot.
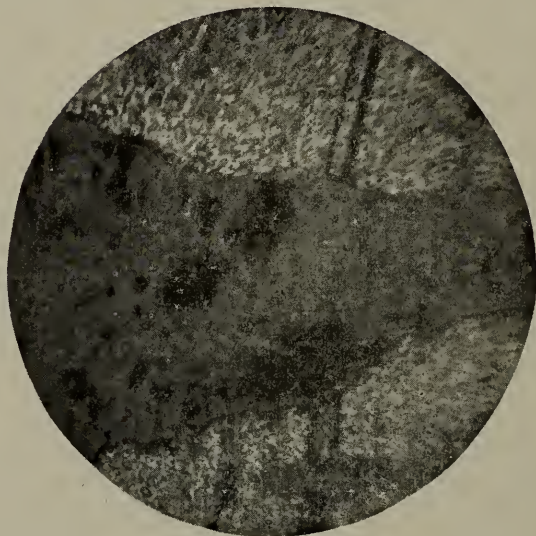
FIG. 13.
Large slag inclusion in low carbon steel.
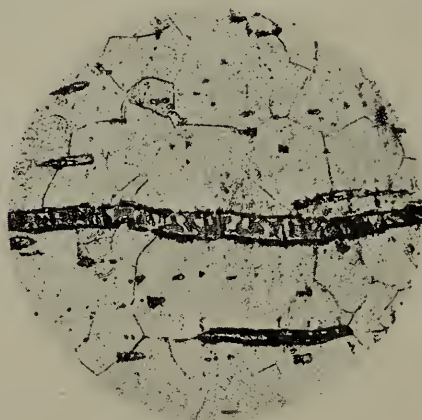
FIG. 14.
Large crystals of Ferrite and enclosed slag in low carbon steel.
Reduced one-half from original of 1000 Diameters.

Below are a few micro-photographs, Figs. 13, 14, 15, which show some of the common impurities which cause considerable trouble when found in steel.

MECHANICAL TREATMENT OF STEEL

The principal purpose of working steel is to shape it into the desired form. Its structure and physical properties are dependent on the care in working and the heats used. The mechanical working, aside from machining, is
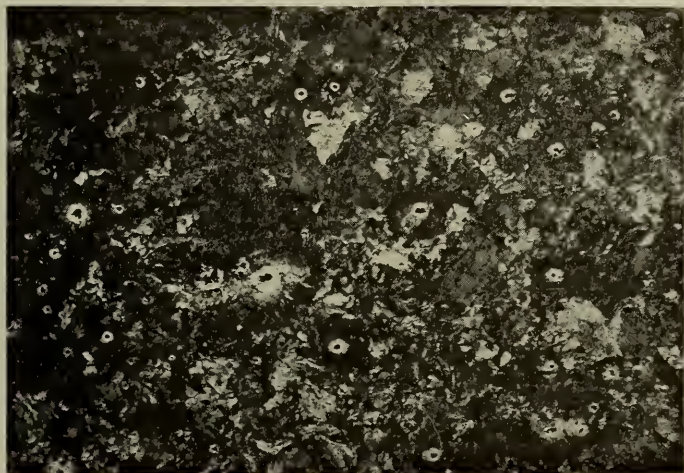
FIG. 15.
Spring steel showing slag.

classed under two heads, namely, "Hot" and "Cold" Working.

The finest grain size obtainable is undoubtedly that existing just as the steel has passed through the critical range on a rising heat. Hence, starting out with steel just below its solidification on undisturbed cooling the grain size increases until the cooling has passed through the critical range, and the grain size, at this stage, will be the resultant size at the cold temperature. Taking the same piece of steel, for instance, having a coarse struct-

ure, on heating there will be no change in grain size until the critical range is reached; there the coarse crystals break up and at the upper critical point form the finest possible structure. Continued heating, however, above this point will again coarsen the grain.

As we have stated, undisturbed cooling is a condition necessary for crystal growth, a coarsely crystalline structure, however, can be partly prevented or broken up by vigorous hammering. If this hammering ceases above the critical range, coarse crystallization again sets in, and the higher the temperature above the critical point at which the work stops, the coarser the structure will be. The finishing temperature in working, then, should be for the best results at or just above the critical range.

The question then arises, Why not continue working the steel until it is cold? This would be a detriment, inasmuch as the grain structure is formed in the critical range and "cold working" below critical range causes distortions and strains to set up in the grain which result in decreased ductility and even brittleness. This effect is more pronounced the lower the temperature below the critical point at which the steel is worked. Mechanical working above the critical range provides a means to shape steel to form by forging, refines the grain size and tends to impart decidedly more density than the steel possessed originally when rolled at the mill.

High-grade steels are hammered at the mills into bars and rolled to proper size.

It will be seen from the following illustrations what is meant by mechanical working and the effect it has on the grain structure.

It is, of course, difficult to show this effect by means of micro-photograph, so the pen is resorted to as a means of explaining the points more clearly.

Fig. 16 shows the grain of steel in the ingot, forgetting for the time the possible conditions entering in steel in this form, such as segregations, pipes, etc. The illustration is just a cross section, before working, of a low

carbon forging steel. The subsequent illustrations are self-explanatory, namely, Fig. 17 shows the ingot rolled or hammered, and the reduction in size of grain is seen.

FIG. 16.
Ingot of Steel.
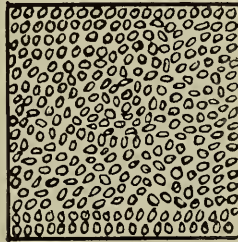
FIG. 17.
Rolled and hammered.
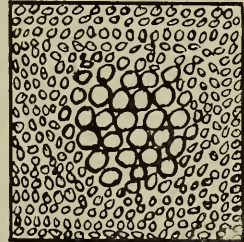
FIG. 18.
Light blows.
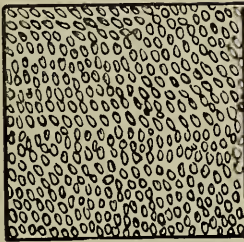
FIG. 19.
Annealed.
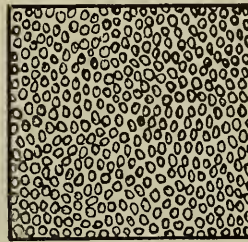
FIG. 20.
Properly hardened.
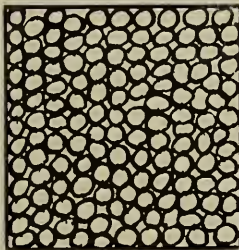
FIG. 21.
Overheated.

FIG. 22.
Restored by hammer-
ing or heat treatment.

Effect of mechanical working on grain structure.

Fig. 18 shows the effect of improper working, the result
of light blows on the surface, which do not extend their
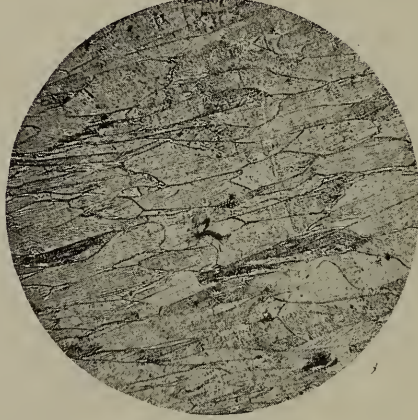
FIG. 23A.
Elongated Crystals.

reducing force to the center; but this is remedied by
annealing (Fig. 19), which promotes the adjustment of
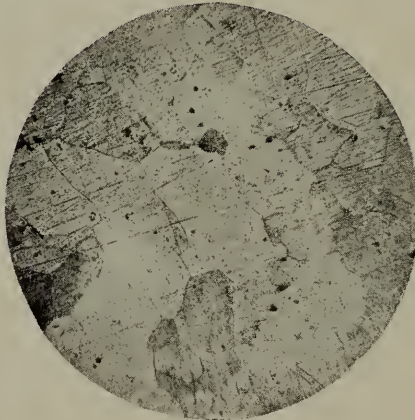
FIG. 23B.
No distortion of Crystals.

the grains and relieves the strains in working. The steel
is now in a condition to be properly hardened, and a fine,
even, silky grain is the result if the proper temperature
and bath have been used in hardening (Fig. 20). If no

high temperature is used in hardening a coarsely crystal-
line formation appears (Fig. 21), which can only be re-

Fig. 23c.
Compressed Crystals.
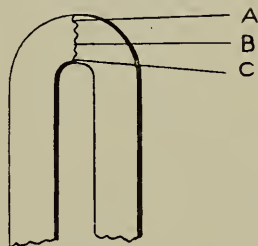
Fig. 23d.
Low carbon Swedish Iron bent double on itself, showing location of
sections illustrated in Figs. 23A, 23B and 23C.

stored, provided the piece permits, by working or ham-
mering and proper heat treatment afterward (Fig. 22).

A simple example of cold working is plainly shown in
the three micro-photographs 23A, 23B, 23C. This shows
the grain distortion at points A, B, C of a piece of low
carbon Swedish iron when bent double on itself, Fig.
23D.

CHAPTER V

ANNEALING

Inasmuch as the annealing process has an important bearing upon its physical properties, its mechanical treatment and its subsequent effect on the heat treatment of steel after machining, it is essential that the basic principles of this operation be thoroughly understood.

The purpose of annealing steel is, first, to increase its softness and ductility and facilitate subsequent machining operations; second, to remove existing coarseness of grain and secure a desirable combination of strength, elasticity and ductility for the resisting of strains; and, third, to relieve internal stresses, such as are induced by forging, rolling, machining, or by non-uniform contraction in cooling.

These changes of physical properties are due to the changes of structure caused by the heating operation, which operation consists essentially of three parts: First, heating the steel to the desired temperature; second, holding at the temperature until the steel is thoroughly heated; third, cooling.

Since all crystallization is changed in heating steel through the critical range, it is necessary, then, to heat the steel through this range as the first step in the annealing operation. Heating to a temperature below the critical range will induce no structural change whatever, but heating considerably above the range will again bring about a form of coarse crystallization, which is detrimental.

For the relief of strains, only, it would be necessary simply to anneal at the lowest possible temperature,—for

instance, at 482° C. (900° Fahr.) to 537° C. (1000 Fahr.) —and if the work must be maintained bright or scaleless, this anneal would be best conducted in a non-oxidizing atmosphere, in closed pots, in the presence of carbon monoxide gases, charcoal or other substances. For strain
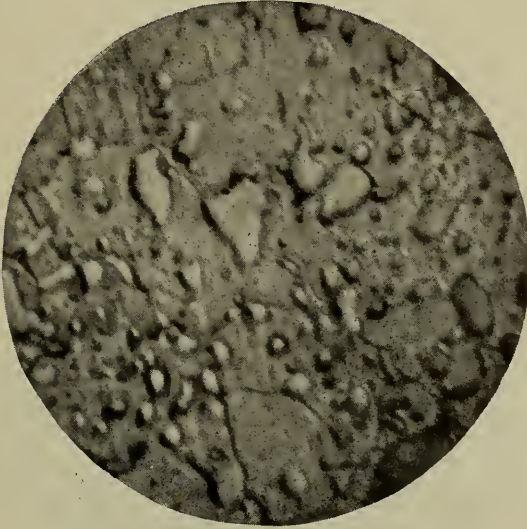
FIG. 24.
Globular Cementite. Magnification, 1000 Diameters.
Carbon content, 1.05 per cent. Annealed at Ac1.
Slowly cooled in furnace.

anneal we do not care particularly if the micro-structure shows lamellar or globular Pearlite.

For free machining or cold work a structure of considerable softness and free shearing properties is desired. It appears that this can best be attained in high carbon steels by heating the steel just below the critical range, maintaining this temperature for some time, and then cooling very slowly without the presence of drafts, especially through latter part of Ar1 range. The micro-structure will show globular Cementite, as in Fig. 24— that is, the hard constituent (Cementite) will not then lie in layers, which are penetrated by the tool with difficulty in machining, but will lie like shot in a box in

such a way that the Ferrite may be very readily cut and the Cementite (in globules) pushed aside. Where steel is subject to severe distortion in cold working, this condition is essential, as it allows Ferrite to flow freely into the new form without the splitting, so common when laminated Pearlite appears, as in Fig. 25.

Lower carbon steels may be too soft in the globular Cementite condition and to machine properly require be-
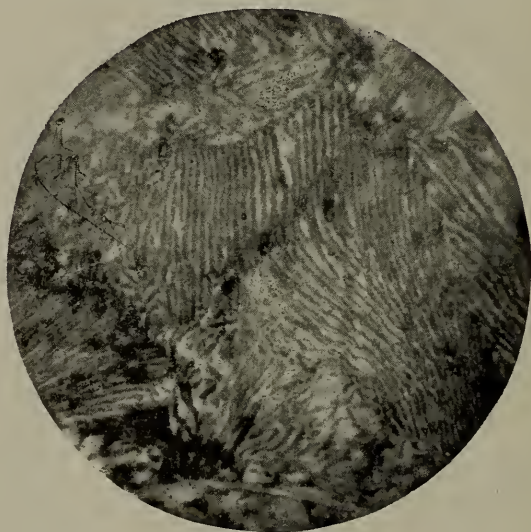
Fig. 25.
Laminated Pearlite. Carbon content, 1.05 per cent.
Annealed above Ac1. Cooled slowly.
Magnification, 1000 Diameters.

ing left in the lamellar form. This is due to the predominance of soft Ferrite in these steels with such a scarcity of Cementite stiffener that it becomes necessary to prevent the flow of the iron under the tool by the lines of stiffening Cementite in the form of Pearlite, and to obtain this proper cutting condition in very low carbon steels it sometimes becomes necessary to air or even oil quench rather than cool slowly.

When chrome steels are annealed they are frequently treated to a preliminary normalizing operation; that is,

they are heated above the critical range to remove unequal working strains and to refine the grain. Then they are cooled below the critical range and finally annealed at the low critical temperature.

The following ranges of temperatures are recommended by the Committee on Heat Treatment of the American Society for Testing Materials:—

Range of Carbon Content	Range of Annealing Temperature
Less than .12 per cent	875° to 925° C. (1607° to 1697° F.)
.12 to .29 per cent	840° to 870° C. (1544° to 1598° F.)
.30 to .49 per cent	815° to 840° C. (1499° to 1544° F.)
.50 to 1.00 per cent	790° to 815° C. (1454° to 1499° F.)

They also state that for steels of a manganese content greater than .75 per cent. slightly lower temperatures are advisable.

The time at which the steel should be held at an annealing heat is governed largely by the size of the piece. In order to bring the interior of large objects to an effective annealing temperature the outside may often be heated advantageously somewhat above the desired temperature. Therefore, a range of temperatures is given for each range of carbon content.

The upper limit of this range applies to larger objects and also to the lower range of carbon content given.

Owing to the annealing process generally being a long one and the cooling slow, there is a great opportunity for scale (iron oxide) to form on the descending heat, owing to the contraction of the furnace gases, in cooling, drawing in air; hence, if scale is to be prevented this air must be kept from the work by closed receptacles. The prevention of heavy scale, due to cooling from too high temperature in the presence of oxygen, is extremely important in the case of the higher carbon steels where the presence of oxide and heat will serve to oxidize the carbon in the metal nearest the scale (decarbonize) often to an injurious degree.

A thick scale (iron oxide) always represents a depth deprived of carbon with a deposit of iron oxide residue.

4

Carbon oxidizes very rapidly, and when decarbonization appears at the surface of hardened steel we find that the carbon content of the steel has been lowered for a considerable distance beyond the depth the fracture would indicate.

The control of the annealing operation by definite heats and methods unquestionably prepares steel to respond

Fig. 26.
Slip band caused by burning.

better to hardening and treating, reduces the strains and distortions which are inevitable and paves the way for a more uniform finished product.

In forging or hardening the control of the heats has been shown to be highly important. In forging if the work is heated too high the operation of forging tends to restore correct conditions. The annealing heat, however, is usually of such duration that unless cared for the heat will rise and the grain size will greatly enlarge. If carried on further the steel will burn, which will cause fissures, gas holes in the structure which weaken the steel by the loss of cohesion of the crystals and on further working or strain slip bands are developed. Fig. 26

shows this clearly. The large dark area is a slip band caused by burning.

At times the previous work of forging may have been finished at so high a point above the critical range that the structure is exceedingly coarse. Annealing at Ac1 will not refine this grain, but if this steel is first heated to Ac3 or above, quenched and then annealed at Ac1 and cooled slowly, the resulting structure will thereby be refined unless the steel has been burned.

CHAPTER VI

PHYSICAL PROPERTIES

The object of heat treatment is to impart to steel certain physical properties to best suit it for a specific use. For the present, we will consider only those physical properties as are generally specified; namely, tensile strength and hardness values, together with a brief sketch of the manner of testing and securing comparative readings in definite units. We will also show how these tests assist in securing the production of large quantities of machine parts of uniform physical properties.

The effect of the additional elements which we know steel to contain and their influence on the temperatures used in treating will be considered under a different heading.

Tensile Properties

In referring to the tensile properties of steel, one usually implies those properties of the material known as the "Elastic Limit," the "Maximum Strength," the "Elongation," and the "Reduction of Area."

A "Stress" is an internal force that resists the change in shape and size of any material by an applied force, and when the applied forces have reached their final values the internal stresses hold them in equilibrium. The simplest case is that of a rope, at each end of which a man pulls with a force, say 25 pounds; then in every section of the rope there exists a stress of 25 pounds. Stresses are measured by the same units as those used for the applied forces, and generally in pounds.

A "Bar" is a prismatic body having the same size throughout its length. If a plane is passed normal to the

bar, its intersection with the prism is called the "cross section" or the "section" of the bar, and the area of this cross section is called the "sectional area."

A "Unit Stress" is the stress on the unit of the section area, and this is usually expressed in pounds per square inch. For example: Let a bar, 2 inches square, be subjected to a pull of 4,000 pounds; the resisting stress is 4,000 pounds and the unit stress is 4,000 pounds divided by the area of the bar, which is 4 square inches, or 1,000 pounds per square inch. When external forces act upon the ends of a bar, in a direction away from its ends, they are called "Tensile Forces." When they act towards the end they are called "Compressive Forces." A pull is a Tensile Force and a push is a Compressive Force, and these two cases are frequently called "Tension" and "Compression." The resisting stresses receive similar designations. A Tensile Stress is that which resists tensile force. A Compressive Stress is that which resists compressive force.

The terms "Axial Forces" and "Axial Stresses" are used to include both tension and compression acting upon a bar along the axis of the bar. The first effect of axial load is to change the length of the bar upon which it acts. The deformation of a bar which occurs in tension is called the "Elongation," and that which occurs in compression is called "Shortening."

When a bar is subjected to a gradually increasing tension the bar elongates, and up to a certain limit it is found that the elongation is proportional to the load. Thus when a bar of wrought iron one square inch in sectional area and 100 inches long is subjected to a load of 5,000 pounds, it is found to elongate close to .02 inch; when 10,000 pounds are applied the elongation is .04 inch; when 15,000 pounds are applied the elongation is .06 inch; at 20,000 pounds the elongation is .08 inch; at 25,000 pounds the elongation is .10 inch. Thus far each addition of 5,000 pounds has produced an additional elongation of .02 inch, but when the next 5,000 pounds are

Curve Showing the Tensile Strength of Wrought Iron.

Ultimate Strength

Yield Point

Elastic Limit

UNIT ELONGATION   0.002"   0.004"   0.006"   0.008"   0.010"

40.000   30.000   20.000   10.000   0

UNIT-STRESS IN POUNDS PER SQUARE INCH
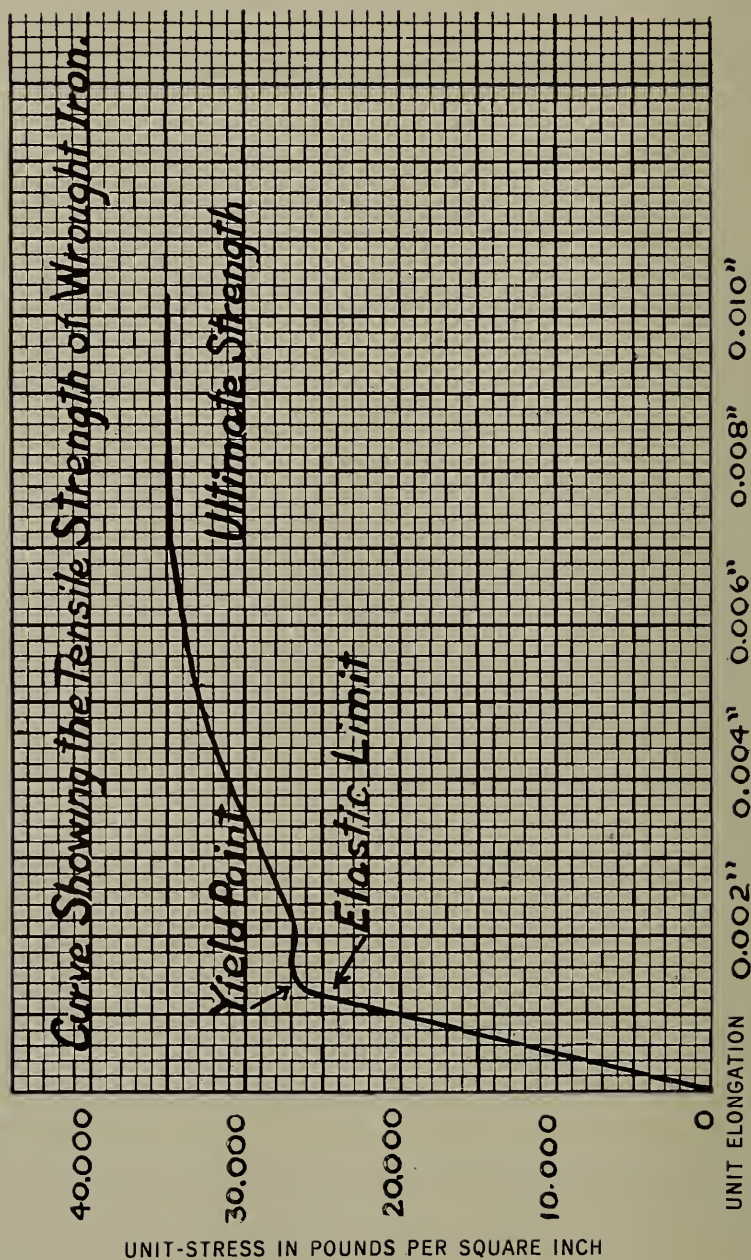
Fig. 27.

added, making a total of 30,000 pounds, it is found that the total elongation is about .50 inch, and hence the elongations are increasing in a faster ratio than the applied loads and the resisting stresses.

The "Elastic Limit" is defined as that unit stress at which the deformation begins to increase in a faster ratio than the applied load. In the above example this limit is about 25,000 pounds per square inch, and this is the average value of the elastic limit of wrought iron.

When the unit stress in a bar is not greater than the elastic limit, the bar returns on the removal of the load to its original length. Thus the above wrought iron bar was 100.10 inches long under the load of 25,000 pounds, and on the removal of the load it returned to its original length of 100 inches. When the unit stress is greater than the elastic limit, the bar does not fully return to its original length, but there remains a so-called "Permanent Set." For instance, let the length of the above bar, under a stress of 34,000 pounds, be 102 inches, and on the removal of the tension let its length be 101⅞ inches. Then the permanent set of the bar is 1⅞ inches.

The "Maximum Strength" is the greatest stress which the material will bear before breaking. This corresponds to the actual breaking weight in hard steels, but in soft steels the actual breaking weight is often considerably less.

The "Elongation" of a bar is determined by making two marks upon it before it is subjected to tension, and measuring the distance between them before and after the test. The difference between these lengths, divided by the original length, gives the elongation per unit of length. For example: If the distance between the two marks is 2 inches and if it becomes 2.60 inches after the rupture, then the total elongation is .60 inch in 2 inches and the elongation per unit length is .30 inch, or 30 per cent.

An elongation of a bar is always accompanied by a reduction in the area of its cross section. The term "Re-

duction of Area" refers to a ruptured specimen, and means the diminution in sectional area per unit of original area. Thus, if the original area of a specimen is .200 square inch, and the area of the ruptured section is .080 square inch, then the reduction of area is .120 square inch, which, when divided by the original area, gives .60, or 60 per cent. The reduction of area is an index of the ductility of the material, and is generally regarded as a more reliable index than elongation, because the elongation is subject to variations with the ratio of the length of the specimen to its diameter, whereas the reduction of area is more constant.

A "Tensile Test" of a vertical bar may be made by fastening its upper end firmly with clamps and then applying successive loads to its lower end. The elongations of the bar are found to increase proportionately to the loads, and hence also to the internal tensile stresses, until the elastic limit of the material is reached. After the unit stress has exceeded the elastic limit the elongation increases more rapidly than the loads. On soft material one will note a marked elongation at the yield point, and on a testing machine this is usually accompanied by a so-called "Dropping of the Beam." Elongation is accompanied by a reduction of area of the cross section of the bar. Finally the maximum strength of the bar is passed and it breaks. The load at the yield point, which, as mentioned above, is commonly accepted as the commercial elastic limit, divided by the original section area gives the unit stress; the load which produced the maximum strength of the bar when divided by the original section area gives the ultimate unit stress. The elongation and reduction of area are then measured and calculated as mentioned above; thereby one determines the tensile test values of the bar.

METHODS OF TESTING THE HARDNESS OF METALS

What property in iron and steel is of more importance than that of hardness? In some cases, as with a cutting

tool or a punching die, the metal is practically worthless
unless it can retain a sharp edge, while in other instances
where the material has to be machined or cut and trued to
shape, even a relatively slight increase of hardness is the
cause of much inconvenience and expense. In a third
class of material a good wearing surface is of prime im-
portance, while lastly hardness may often serve as an in-
dication of a degree of brittleness and untrustworthiness
which might perhaps be otherwise unsuspected.

Hardness may be defined as the property of resisting
penetration or abrasion, and conversely a hard body is
one which, under suitable conditions, readily penetrates
a softer material. There are, however, in metals, various
kinds of manifestations of hardness according to the form
of stress to which the metal may be subjected. These
include tensile hardness, cutting hardness, abrasion hard-
ness and elastic hardness. The usual quantitative tests
for hardness are static in character, but the conditions
are profoundly modified when the penetrating body is
moving with greater or less velocity. The resistance to
the action of running water, to the effect of a sandblast,
or to the results of the pounding of a heavy locomotive
on a steel rail, afford examples of what might perhaps
for purposes of distinction be called dynamic hardness.

Five typical methods of measuring hardness include
the sclerometer, introduced by Turner; the scleroscope,
invented by Shore; the form of indentation test adopted
by Brinell, the drill test introduced by Keep, and the
Rockwell test. The principles underlying the five meth-
ods selected for comparison may be briefly described as
follows:

Turner's Sclerometer

In this form of test a weighted diamond point is drawn
once forward and once backward over the smooth surface
of the material to be tested. The hardness number is the
weight in grammes required to produce a standard scratch.
The scratch selected is one which is just visible to the

naked eye as a dark line on a bright reflecting surface,
or it is the scratch which can just be felt with the
edge of a quill when the latter is drawn over the smooth
surface at right angles to a series of such scratches pro-
duced by regularly increasing weight.

SHORE'S SCLEROSCOPE

In this instrument a small cylindrical hammer of steel,
with a diamond point, enclosed in a glass tube graduated
in arbitrary units, is allowed to fall upon the smooth
surface of the material to be tested. The hardness num-
ber is the height of the rebound of the hammer. The
hammer weighs slightly over two grammes. The height
of the rebound of hardened steel is in the neighborhood
of 100 on the scale, or about 160 millimeters, while the
total fall is about 10 inches, or 225 millimeters.

BRINELL'S TEST

This method is founded upon the effect produced on a
substance by a known load pressing a ball into the sur-
face of the material to be tested. The hardness numbers
are found by the use of certain factors and coefficients,
and are only arbitrary comparable units, indicating suffi-
ciently different conditions in the materials tested; they
are taken from practical experience rather than from sci-
entific knowledge.

The method of working is as follows: The weight
or load given in kilograms is generally 3000 for iron
and steel and 500 for softer metals and alloys. The
pressure is applied hydraulically by means of an oil pump
and is transmitted through the plunger to a hardened-steel
ball, which makes a cup-shaped impression on the test
piece. From the diameter of this impression and the
load a working formula has been deduced, and a table
of hardness numbers computed.

The formula is as follows:

$$H = \frac{3000}{\frac{\tilde{n}\,D}{2}\,(D - \sqrt{D^2 - d^2})}$$

where

$H =$ Hardness;

$D =$ Diameter of ball (10 millimeters);

$d =$ Diameter of impression.

The diameter of the impression is read off by means of a microscope, having a micrometer scale, graduated in tenths of a millimeter, contained in the diaphragm of the eye-piece. A verifying scale is supplied with the microscope.

Example: Let the diameter of impression $= 4.7$ mm., then

$$H = \frac{3000}{\frac{31.416}{2}\,(10 - \sqrt{100 - 22.09})}$$

disregarding further decimal points

$$= \frac{3000}{15.708 \times 1.17} = \frac{250}{1.309 \times 1.17} = 163 \; hardnesss \; No.$$

This formula is not quite accurate, since it does not take into consideration the mass of material displaced but only the superficial area of the impression, yet it is perhaps the simplest working formula.

KEEP'S TEST

In this form of apparatus a standard steel drill is caused to make a definite number of revolutions while it is pressed with a standard force against the specimen to be tested. The hardness is automatically recorded on a diagram on which a dead soft material gives a horizontal

line, while a material as hard as the drill itself gives a vertical line, intermediate hardness being represented by the corresponding angle between 0 and 90 degrees.

Each form of test has its advantages and its limitations. The sclerometer is cheap, portable and easily applied, but it is not applicable to materials which do not possess a fairly smooth reflecting surface, and the standard scratch is only definitely recognized after some experience. The Shore test is simple, rapid and definite for materials for which it is suited. As shown by De Freminville, the result obtained varies somewhat with the size and thickness of the samples, while if the test piece is supported on a soft material, such as plasticine, the results are valueless.

The Brinell test is especially useful for constructive material. It is easily applied and definite and is the hardness test most generally employed; it cannot be applied to very brittle materials, such as glass or hard minerals.

A very important question arises in connection with these various tests; namely, as to whether there is any observed agreement between the results which are arrived at by such entirely different methods. It will be noticed that in each case an arbitrary scale is adopted. If the weight used on the sclerometer had been ounces instead of grammes the hardness numbers would naturally have been different. Similarly Brinell's test might have been expressed in tons and inches, or a definite weight of hammer and height of scale adopted by Shore. Hence, all that can be expected is a proportionality in the results, and if this is ascertained it should be possible to convert values on one scale into results on another. In the following table will be found a comparison of hardness values of various materials. For the purpose of comparison, the actual Brinell hardness values have been divided by 6. The sclerometer and scleroscope values are actual readings. It appears, from a study of the table, that all the instruments with simple homogenous substances give results which are either in actual agreement with or pro-

portional to the results obtained by the other form of apparatus.

Rockwell Testing Machine For Hardness

This machine consists of an anvil and a plunger holding a diamond point. The diamond is forced into the surface of the steel under a constant pressure. The depth of the impression is read direct to 1/10,000 of an inch. The machine is calibrated to give a hardness reading in Brinell numbers or in percentages. Electrolytic iron is taken as Zero per cent. and the diamond as 100 per cent. Hard. It can be used excellently as a comparative tester. Due to its small area of application a great many shapes and surfaces may be tested accurately. Wire can be tested as small as .09 inch diameter. It requires no special preparation of the piece of steel to be tested except in some cases a slight surface cleaning. The depth of indentation can be controlled so that no harm can be done to a finished surface.

TABLE No. I.

HARDNESS VALUES OF METALS.

Metals	Sclerom- eter	Sclero- scope	Brinell
Lead........................	1.0	1.0	1.0
Tin.........................	2.5	3.0	2.5
Zinc........................	6.0	7.0	7.5
Copper (soft)..............	8.0	8.0	....
Copper (hard).............	....	12.0	12.0
Softest Iron...............	15.0	....	14.5
Mild Steel.................	21.0	22.0	16.24
Soft Cast Iron.............	21–24	24.0	24.0
Rail Steel.................	24.0	27.0	26–35
Hard Cast Iron............	36.0	40.0	35.0
Hard White Iron..........	72.0	70.0	75.0
Hardened Steel............	....	95.0	93.0

TABLE No. II.

BRINNELL HARDNESS NUMBERS AND ESTIMATED TENSILE STRENGTH FOR 3,000 KILOGRAM PRESSURE ON A 10 M/M BALL TESTING MACHINE.

Dia. of Impression in m/m	Hardness Numeral	Ultimate Pounds per Sq. In.	Dia. of Impression in m/m	Hardness Numeral	Ultimate Pounds per Sq. In.
2.00	946	465,100	4.00	228	112,600
2.05	898	442,100	4.05	223	109,700
2.10	857	421,600	4.10	217	106,900
2.15	817	402,000	4.15	212	104,200
2.20	782	383,700	4.20	207	101,600
2.25	744	366,600	4.25	202	99,100
2.30	713	350,600	4.30	196	96,700
2.35	683	335,700	4.35	192	94,400
2.40	652	321,600	4.40	187	92,200
2.45	627	308,400	4.45	183	90,000
2.50	600	295,900	4.50	179	87,900
2.55	578	284,300	4.55	174	85,800
2.60	555	273,300	4.60	170	83,900
2.65	532	262,900	4.65	166	82,000
2.70	512	253,100	4.70	163	80,100
2.75	495	243,800	4.75	159	78,300
2.80	477	235,000	4.80	156	76,600
2.85	460	226,600	4.85	153	74,900
2.90	444	218,700	4.90	149	73,300
2.95	430	211,200	4.95	146	71,700
3.00	418	204,100	5.00	143	70,200
3.05	402	197,300	5.05	140	68,700
3.10	387	190,800	5.10	137	67,200
3.15	375	184,600	5.15	134	65,800
3.20	364	178,800	5.20	131	64,500
3.25	351	173,200	5.25	128	63,100
3.30	340	167,800	5.30	126	61,800
3.35	332	162,700	5.35	124	60,600
3.40	321	157,800	5.40	121	59,400
3.45	311	153,100	5.45	118	58,200
3.50	302	148,600	5.50	116	57,000
3.55	293	144,300	5.55	114	55,900
3.60	286	140,200	5.60	112	52,800
3.65	277	136,200	5.65	109	53,700
3.70	269	132,400	5.70	107	52,700
3.75	262	128,800	5.75	105	51,700
3.80	255	125,300	5.80	103	50,700
3.85	248	121,900	5.85	101	49,700
3.90	241	118,700	5.90	99	48,800
3.95	235	115,500	5.95	97	47,900

$$\frac{\text{Pressure}}{\text{Area of Impression}} = \text{Hardness Number}$$

Tensile in Kg. per sq. m/m = coefficient .346 × hardness number
1422.3 Factor to convert Klg. per sq. m/m to lbs. per sq. in.

CHAPTER VII

PYROMETERS

In the heat treatment of steel too great emphasis cannot be laid upon the controlling and regulating of the temperature of heating, whether it be for hardening, drawing or annealing. In the treatment of steels where the critical changes must be determined and the furnace regulated to the predetermined heat we are forced to depend on the pyrometer.

In the heat treatment of steel the types of pyrometers most generally used are the thermo-electric pyrometers and optical pyrometers. Of these two the thermo-electric method is by far the most important.

The theory on which the operation of thermo-electric pyrometers is based is briefly described as follows:

If, when two wires of different composition are joined together at both ends so as to make a complete circuit, one of these junctions be at a different temperature from the other, a difference of electrical potential is set up at the junctions and an electric current flows through the wires. Such a pair of wires is called a thermo-electric couple. If the wires are of uniform composition the potential difference depends upon the difference of temperature alone, and the strength of the current will vary directly as the differences of temperature. If a galvanometer or a millivoltmeter be inserted in the circuit, this current can be measured, and if the current corresponding to various differences of temperature be once ascertained, the apparatus can be used as a means of measuring temperature. The thermo-electric couples are divided into two principal classes: Base Metal and Noble Metal couples.

There appears to be an insistent demand on the part of many in charge of technical processes requiring temperature control for inexpensive and robust measuring apparatus. For this reason, if for no other, the use of the base metal couple has become firmly established and its success lies principally in the production of fairly satisfactory alloys having considerable changes of electromotive-force with small temperature changes, which can be made into strong, practically unbreakable, thermocouples, and the development of an inexpensive fairly robust millivoltmeter.

Practically all the base metal thermal couples in commercial use at present are made of one of the following combinations: iron-copper-nickel; nickel-chrome-nickel-aluminum; or nickel-copper-nickel-chrome.

The former are more efficient when used in furnaces in a reducing atmosphere. The latter are more desirable in an oxidizing atmosphere.

The standard noble metal couple is made of platinum and an alloy of platinum with 10% of Rhodium.

The thermo-electric force of these various base metal couples is quite constant and is in the majority of cases unaffected by furnace gases. Sometimes, however, the materials of the couple may be altered in a uniform manner by the heat and minor errors introduced. Further, the heat of the furnace is almost sure to cause the materials to disintegrate, thus reducing the cross section of the couple and increasing its resistance. This increase in resistance allows less current to flow for a given electromotive force and is the source of serious errors.

It is, therefore, important to frequently check and calibrate a pyrometer consisting of a base metal couple and a millivoltmeter.

The noble metal couple has its advantages. It possesses a fairly linear temperature electro-motive-force relation, especially so between 300° and 1100° C. (572° and 2012° Fahr.). It can be used at temperatures as high as 1500° C. (2732° Fahr.) with great accuracy. Properly

protected it can be retained in a homogeneous condition, so that depth of immersion in the furnace or heating medium brings about little or no error, and on account of its being used in connection with a high resistance galvanometer, errors due to changes in lead resistance and that of the couple itself are usually negligible.

Heating noble metal pyrometer couples to high temperature in a reducing atmosphere causes an alteration of the elements.

Platinum couples must be protected by some form of ceramic case which is impermeable to hot gases, otherwise the couple will be seriously damaged by hydrocarbon gases and metallic vapors from the furnace. The two wires should be insulated from each other by quartz or clay tubing. Avoid the use of asbestos, as the material in its pure form probably has no action, but practically all commercial asbestos available contains impurities which have an injurious effect on platinum.

A couple thus mounted is limited only by the melting point of the protective tube and insulators. These are available up to 1371° C. (2500° Fahr.) but must be used with great care.

An iron tube can be used for protection if the temperature does not exceed 800° C. (1472° Fahr.), in the lead bath serving to harden steel for example, and for movable couples which are exposed to heat only during the time necessary to take the observation. In all cases where the furnace, whose temperature it is desired to measure, is under reduced pressure, suitable precautions must be taken to prevent any permanent entrance of cold air by the orifice necessary for the introduction of the tube, before as well as during an observation. Otherwise, one runs a chance of having inexact results.

In the case of prolonged observations in a reducing atmosphere or in contact with melted bodies, the couples should be protected by enclosing in a covering impermeable to the melted metals and to vapors.

5

Whether the couples be made of base or noble metal, for good, accurate service the wire should be well insulated and the junction of the elements protected from the gases of the furnace, the cold-end junction kept fairly constant, the accuracy of the system checked or calibrated frequently, depending on the temperature and length of time in service (for checking, a standard millivoltmeter and couple is often set aside and used only for the above purpose) and the entire system handled with care, for in the majority of cases errors and false readings, as well as lack of confidence in the pyrometer, is caused by the abuse or wrong use of the apparatus.

CHAPTER VIII

THE THERMAL OR HEAT TREATMENT OF STEEL

The highest priced steel may be so improperly treated that the results or properties obtained are far inferior to a well-treated, cheaper grade of steel. Although these changes, due to the thermal treatment, are governed by definite laws it must be remembered that the same treatment cannot be applied to all steels with satisfactory results, but that each type of steel responds best to its own characteristic temperatures.

The subject of heat treatment embraces the operations of annealing, case-hardening or carburizing, hardening, and tempering or drawing of steels. To obtain the highest physical properties from steel by heat treatment it is necessary for us to have a knowledge of the critical points and transformations occurring.

An improvement in the quality of physical properties of the steel is generally brought about by heating to or through the critical range. Hardening or annealing from temperatures below these points will not be complete, nor will the structure or grain be properly refined. Quenching from temperatures higher than the critical range will result in hardening the steel, but with a coarser grain than if quenching had been done at just above the critical range.

It is universally understood that the finer the grain the stronger the steel, and to obtain this refinement the heating and cooling curves of the steel must be determined and the treatment operation confined as narrowly as possible, with respect to the critical temperatures, else the worth of the steel will be markedly impaired.

These facts about the internal modification of the steel structure present some very interesting viewpoints to the practical man familiar with them. For instance, if a cold piece of steel (the higher the carbon the more aggravated it becomes) is thrown into a raging hot furnace (much above the critical range) the transformation of the Pearlite and the Ferrite, or Cementite into Austenite, is rushed far beyond the capacity of the steel to withstand it, and in passing into the Austenite stage a molecular expansion occurs. Thus the phenomenon of cracking on a rising heat is explained. Similarly, if flame impinges upon the work, the transformation takes place very fast at this point and either cracking or warping must ensue. This is why muffle furnaces and lead or salt baths give much better hardening results as a rule. Besides this, in a salt bath, upon the introduction of a piece, the salt congeals about the work, melts fairly slowly and serves to help in the slowing down of the transformation. Preheating to a medium temperature before insertion in the hardening furnace also helps the steel pass through this critical stage without damage.

Changes of Structure Brought About By Heat Treatment

These changes have been summarized by Brinell about as follows:

1. When a piece of steel, hardened or unhardened, is heated to the upper critical point, Ac3, all previous crystallization, however coarse or however distorted by cold work, is obliterated and replaced by the finest structure which the steel is capable of assuming, the structure of burnt steel being the only exception (the Ferrite and Pearlite or Pearlite and Cementite is changed to Austenite).

2. When a piece of steel, hardened or unhardened, after being heated to Ac3, is allowed to cool slowly, it retains the fine structure which it had acquired at that

temperature. It then possesses the finest structure which *unhardened* steel is capable of assuming. (The Austenite reverts to the original Pearlite and Ferrite or Pearlite and Cementite, but the grains, however coarse originally, become now the finest and best distributed possible.)

3. When a piece of steel, hardened or unhardened, after being heated to Ac3, is suddenly cooled by quenching in cold water, for instance, it is fully hardened and retains the fine grain acquired at that temperature. The metal then possesses the finest structure which *hardened* steel is capable of assuming.

(The Austenite, which tends to rapidly revert through several stages to Pearlite, etc., is trapped before reaching the soft Pearlite stage and the resulting structure is composed of Martensite—the hardest stage in steel, save the Cementite, and the condition of greatest volume.)

4. When a piece of steel, hardened or unhardened, is heated to a temperature *above* Ac3 and cooled slowly, the metal whose crystallization has been obliterated by its passage through Ac3, crystallizes again, the crystals or grains increasing in size until Ar1 is reached, below which there is no further growth.

If steel is heated above Ac3 and allowed to cool to Ac3 again and there quenched, it will be fully hardened, but its structure will be coarser than if it had been quenched from Ac3 without having been heated higher.

5. The higher the temperature above Ac3, from which the steel is cooled or quenched, the coarser the grain.

6. The slower the cooling from above Ac3 the coarser the grain.

7. When a piece of hardened steel is heated to a temperature below Ac3 some of its Cementite is changed spontaneously into Pearlite and the metal is thereby softened. This tendency increases with the temperature and is greatest at Ac1. This transformation, however, is not accompanied by a change in the dimension of the grain.

Our researches and the recent work of Professors Howe and Zimmerschied have developed that:

1.   When a piece of steel, hardened or unhardened, is heated to the temperature Ac_1, the Cementite existing in the Pearlite structure is radically altered from the previous laminated to the globular state, the resultant structure is thereby softened and rendered ductile, and the size of the grain is unchanged.

2.   When a piece of steel, previously heated to Ac_3 and then either hardened or allowed to cool slowly, is thereupon heated to Ac_1 and allowed to cool slowly, especially through the lower Ar_1 range, the resultant structure shows globular Cementite and is the softest and most ductile that steel may assume, the size of the grain being the smallest possible.

CHAPTER IX

CARBURIZING

Carburizing has risen in the past ten years from a practice of which very little was written and very little known to a position that has assumed great commercial importance, due primarily to the rapid development of the motor car industry.

It is the demand of this industry to meet the development where greatest strength and minimum weight are essential that has given the impetus to the marked advance in metallurgy, making necessary a corresponding improvement in heat treating practices in both alloy and straight carbon steels. While present-day methods produce results revolutionary in comparison with those of only a few years past, the science is far from being a completed one today.

With the knowledge that present-day methods may in turn be discarded a few years hence this work is submitted. It contains the most up-to-date practices today and is intended to act merely as a guide from which the individual hardener may select the information that will be most helpful in his particular case.

The theory of carburizing depends upon the fact that steel and iron has such strong affinity for carbon that when heated in a sealed receptacle in contact with carbonaceous material the carbon gas is absorbed by the metal.

The operation of carburization implies that the user in a sense makes his own steel, and the details of the operation must be thoroughly understood so that it may be conducted with a minimum cost and with the maximum certainty and regularity.

Investigation has proved that the advantages accruing from case carburizing make it the most efficient manner of obtaining the desired physical properties in many cases.

Opinions vary as to the theory of the absorption of carbon by the metal. The carbon may combine with the iron at the surface to form carbides which diffuse in the metal, or the carbon may be diffused in a gaseous condition, the gas giving up its carbon to the metal.

Whatever may be the method, the facts indicate that the best results are obtained when carbonaceous vapors or gases are present.

The process of carburizing is one which consists of adding such a percentage of carbon to an outside layer of steel as will, on correct quenching, produce a hardened surface, while the inner core of the metal retains its initial character.

In carburizing we desire to control two factors: First, the depth of the carburized zone; second, the graduation of the carbon content from the outer surface to the core.

The percentage of carbon and the depth of penetration are dependent upon, first, the composition of the steel subjected to carburization; second, the carburizing temperature; third, the length of time the steel is allowed to remain at the carburizing heat; fourth, the nature of the carburizing material used.

Composition of Steels For Carburizing

It is a well-known fact that low carbon steels are more susceptible to carburization than those of high carbon content, which explains the decreased rate of penetration during the latter part of the carburizing operation.

Then, again, on using low carbon steels for carburization the resultant core remains tough, soft and fibrous and enables the finished product to resist shock.

The initial carbon content of the steel governs the depth of case at which maximum brittleness and minimum strength occur, so that the higher the original carbon con-

tent the lower the ratio of depth of case to the diameter of the core. Therefore, it is important to know that depth of carburizing is partly regulated by the carbon content of the original steel.

Some constituents retard the rate of penetration, others increase it, while some increase brittleness and others reduce it.

The carbon content of the steel should be below 25 point, as the higher the carbon content the greater the brittleness after heat treatment.

Manganese content should be about .35 per cent. or less, as high manganese renders the carburized case brittle and lowers the resistance to shock. Manganese increases the rate of penetration.

If, however, steel with higher manganese content is used, the detrimental effects can be overcome by alloys, such as nickel and chromium.

Silicon retards the rate of penetration; in fact, steels containing over 2 per cent. of silicon will not absorb carbon. In general, it should not exceed .30 per cent.

Phosphorus and sulphur content should be low.

Nickel very materially affects the physical properties, the effect being limited by the amount of nickel and the carbon present.

Nickel lowers the rate of penetration in proportion to the amount present, when in excess of $2\frac{1}{2}$ to 3 per cent.

Vanadium lowers the rate of penetration, but as it is used in such small quantities, its effects in this respect may be disregarded. Its influence on the physical properties is pronounced, and it very materially increases strength, elastic limit and resistance to shock.

Chromium increases the rate of penetration of carbon and reduces the grain size considerably.

It slightly increases the difficulties of machining and forging.

The composition of any steel for carburizing should be regulated for the purpose intended.

A fair analysis of a carbon steel for general work is carbon 10 to 20 point, manganese and silicon less than .35 per cent., phosphorus and sulphur below .04 per cent.

The influence of the different elements on the speed of penetration of carbon, when carburizing steels containing the same amount of carbon and the different percentages of manganese, chromium, nickel and silicon, is shown in the following comparative table:

INFLUENCE OF ALLOYS ON CARBON PENETRATION.

Component of Alloys	Speed of Penetration per Hour in Inches
0.5% Manganese	.043
1.0% "	.047
1.0% Chromium	.039
2.0% "	.043
2.0% Nickel	.028
5.0% "	.020
0.5% Silicon	.024
1.0% "	.020
2.0% "	.016
5.0% "	.000

Carburizing Temperature

The carburizing temperature and its uniformity controls the degree of carburizing.

While the theory has been advanced that carburization may take place at temperatures below the critical range, experience has proved that the low temperatures are very unsatisfactory for commercial work. The slight carburized zone obtained at a temperature of 705° C. to 788° C. (1300° Fahr. to 1450° Fahr.) with the ordinary grades of carburizing steels is lacking in uniformity, low in carbon content and with little graduation.

There are a few special steels, however, principally the chrome vanadium steel, which absorb carbon quite readily at low temperatures.

The carburizing temperature is dependent upon the carburizing material used, inasmuch as some materials will give a 90-point case at 871° C. (1600° Fahr.), 105-point case at 899° C. (1650° Fahr.), 115-point case at
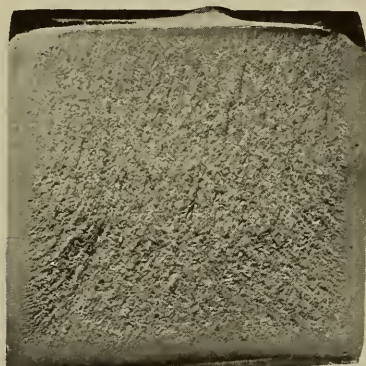

FIG. 28.
Depth of Penetration.
Carburized twenty-four hours at 874° C. (1605° Fahr.).
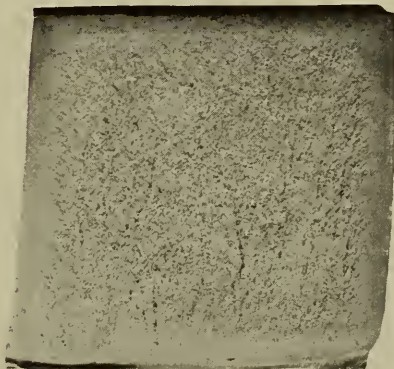
FIG. 29.
Depth of Penetration.
Carburized twenty-four hours at 925° C. (1697° Fahr.).

927° C. (1700° Fahr.), while other materials may give a 90-point carbon case at 927° C. (1700° Fahr.).

It is absolutely necessary to be thoroughly familiar with the carburizing material, the results obtained at certain heats, length of time required to obtain a certain

depth of penetration at that temperature, and whether the heats used will injuriously affect the steel.

A temperature of 899° C. (1650° Fahr.) is best for most purposes, taking into consideration the demand for

FIG. 30.
Depth of Penetration.
Carburized twenty-four hours at 1010° C. (1850° Fahr.).

quick carburizing, with retention of the physical properties of the steel.

The carburizing temperature influences the depth of penetration. The higher the temperature used in carburizing the greater the depth of penetration, as shown in Figs. 28, 29 and 30. Fig. 28 represents a piece of steel carburized for 24 hours at a temperature of 874° C. (1605° Fahr.), and shows the least penetration, whereas the piece carburized for 24 hours at a temperature of 925° C. (1697° Fahr.), shows a decided deeper penetration of case (Fig. 29) and Fig. 30, which was carburized for 24 hours at a temperature of 1010° C. (1850° Fahr.), gives the deepest case of all.

In hastening the carburizing operation the furnaces may be heated to 50° Fahr. above the carburizing temperature until the pots are heated throughout and then lowered to the correct carburizing temperature.

After the carburizing pots have been heated throughout the heat must be kept as uniform as possible, so as to obtain the best results.

In commercial work, however, there are so many things to be taken into consideration that we think it best to summarize the effects of the temperature and thus allow our readers to make their selection.

As a further aid to the hardener, the specifications of the American Society of Automotive Engineers are given at the close of this treatise. It will be seen that the general characteristics are given, together with the heats for carburizing and heat treatment. These heats are approximate, but in very close range for proper refining.

The Depth of Penetration

The depth of penetration in a given time, as well as the carbon content or percentage of carbon in the carburized zone, is governed by the temperature used in carburizing and the length of time the work is held at the carburizing heat.

The higher the temperature used in carburizing the greater the depth of penetration and the higher the carbon content of the carburized case, all of which has been proved by tests made by heating the same work under the same conditions but increasing the carburizing temperature for each new heat or test.

The lowest temperature at which uniform penetration can be obtained is about 816° C. (1500° Fahr.).

Work which is not "subjected to shock," but requiring the greatest wearing surface, can be carburized at a temperature of 927° C. (1700° Fahr.), with a suitable carburizing material to obtain a carburized case of Hyper-Eutectoid composition or 115-point carbon, as shown in Fig. 31.

This micro-photograph shows the black areas as Pearlite and the white areas surrounding the Pearlite as excess carbide or "Free Cementite."

Such parts as ball and roller bearings, which require
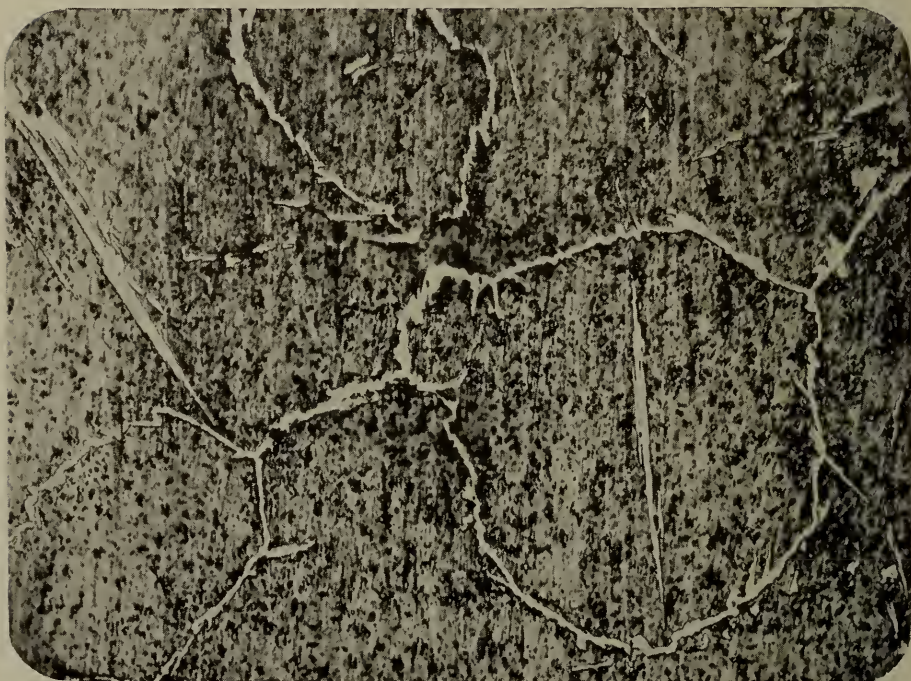the toughest possible case with the greatest hardness,

Fig. 31.
Dark Areas, Pearlite.
White lines, Excess Carbide or "Free Cementite."

should be carburized at 900° C. (1652° Fahr.), so as to
obtain a carburized case of Eutectoid composition or 90-
point carbon, as shown in Fig. 32, since the presence of
"Free-Cementite" in the carburized case would produce
brittleness when subjected to shock and heavy load.

For a given time and temperature the chrome steels
seem to give the greatest depth of penetration, as well as
the highest carbon content.

Graduation of case into core increases with the in-
crease of temperature in carburizing, attaining a maxi-
mum at about 912° C. (1675° Fahr.). Grain size of the
steel increases with increased temperature.

Alloy steels, especially chrome vanadium, show the least coarse crystallization at high temperature.

Conditions in working, cost of hardening, haste for parts needed in production, etc., necessitate that the practical man make a close study of his work. Results, while not carrying the steel to the highest degrees of hardness, but sufficient for present needs, can be obtained by a close study of the effect of high carbon case, light or thin penetration, quenching directly from the carburizing pot, or allowing the work to cool in the pots and reheating to the hardening temperature.

The above methods are used by many hardeners, knowing that they are not obtaining the greatest efficiency in the piece treated, but time, conditions in the shop and the cost of production are the excuses for hastening or changing the method to obtain the best possible results, such as cooling in the carburizing pot and heating for core refinement, heating for case refinement and drawing, if necessary.

A carburized case of great depth and high carbon content may cause warpage, cracking and brittleness on small parts, while a thin, low carbon case is of no value to the work other than the benefit the piece receives from the heating and quenching.

The selection of the best carburizing temperature to obtain uniform work of the highest standard requires consideration of the composition of the steel to carburize, shape of the boxes, fuel, cost of production, etc., all of which we can touch lightly, leaving much to the judgment of the individual to regulate conditions under his control.

The microscope plays an important role in determining the depth of the carburized case and also the carbon content of the case. It is possible by microscopic examination of steel, which has been annealed and cooled slowly, to determine the percentage of carbon. The carburized case can be divided into three classes:
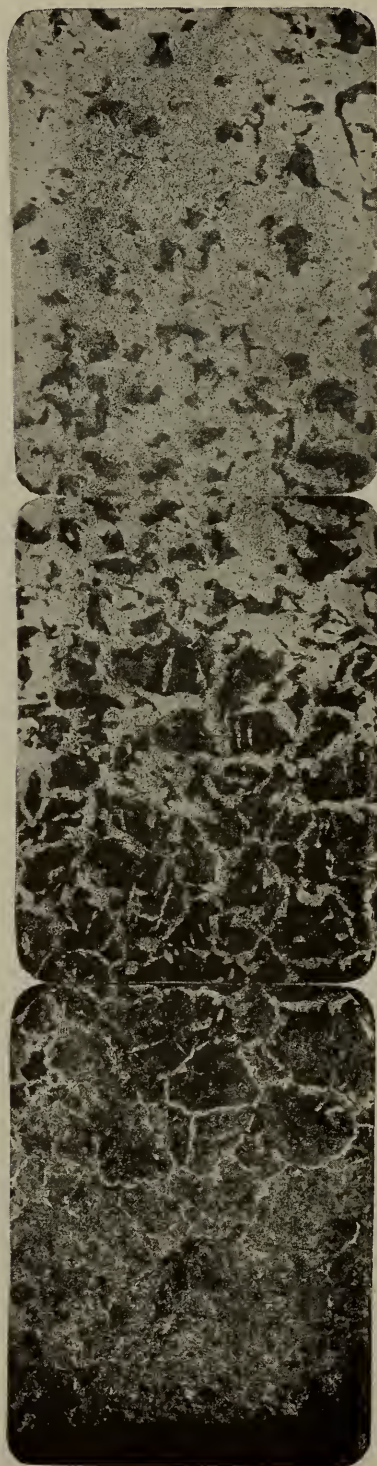
Graduation of Carbon from case into the core.
Magnification, 100 Diameters.
Fig. 32.

Carburized case of
90-point Carbon.

First, the Hypoeutectic layer in which the amount of carbon is less than .85 per cent., as shown in Fig. 32.

Second, the Eutectic layer containing .85 to .90 per cent. carbon, as shown in Fig. 32.

Third, the Hypereutectic layer in which the amount of carbon exceeds .85 per cent., shown in Fig. 32.

To prepare a piece of carburized steel for examination cut in two and polish the cross section with two or three grades of emery wheels or emery paper, finishing with the finest grade, and finally with rouge, until a mirrorlike finish is obtained. The polished section is then immersed in a solution of 10 parts picric acid and 90 parts alcohol, or 5 parts nitric acid, 95 parts alcohol for 30 seconds. The carburized layer will be darkened by the action of the acid, and the three zones, hypoeutectic, eutectic and hypereutectic, will show up distinctly.

6

CHAPTER X

CASE-HARDENING

The factors which control case-hardening are: First, carburizing materials used; second, style of boxes and method of packing; third, the temperature reached; fourth, the length of time held at this temperature; fifth, the heat treatment after carburizing; sixth, the method of hardening, quenching and tempering; seventh, the character of the metal treated.

A molten bath of potassium cyanide heated to 850° C. (1562° Fahr.), and in which the steel articles are immersed, produces quick, superficial, hard and even cases. The poisonous character of the escaping gases, however, is a serious objection to its use.

The carburizing of steel may also be performed at the proper temperature by means of gases, such as illuminating or other gases rich in hydro-carbons. There are a number of commercial mixtures offered for sale, all of which possess some or a number of good virtues.

A perfect carburizing material should possess the following virtues:

First—Should carburize quickly, so that the heating will be extended over the shortest possible time.

Second—It must be homogeneous.

Third—It must carburize at a uniform rate.

Fourth—It must give a uniform carbon content.

Fifth—It must not exhaust itself too quickly; that is, it must be capable of being used over and over again without complete renewal of fresh material.

Sixth—Must be free from sulphur and moisture.

CHAPTER XI

CARBURIZING MATERIAL

A fairly rapid heating carburizing material may, in some instances, be desirable; it is by no means essential. The rate of penetration of carbon in any grade of steel is normally governed by the temperature used in carburizing and the carburizing gases liberated by the material at the carburizing temperature.

The effect of increasing the temperature is to increase the solubility of the carbon in the steel.

All carburizing mediums do not give the same rate of penetration at the same temperature.

Charcoal and coke are not so rapid as leather, bone and other compounds rich in hydro-carbons.

The freedom with which the carburizing gases are liberated depends entirely upon the composition of the mixture and the form in which the carbonaceous material exists. It is generally conceded that carbon monoxide is the true carburizing gas, and is developed from solid carburizers by the influence of heat—indirectly from the decomposition of hydro-carbon vapor and cyanogen and directly from the oxidation of the fixed carbon. The hydro-carbons and cyanogens are much more easily volatilized by heat than the fixed carbons, which are more graphitic in their nature, especially those of mineral origin.

A compound may thus have a high heat conductivity and yet, being composed largely of fixed carbon, will not liberate and form the carburizing gases in any quantities until the higher temperatures are reached. It is not correct, therefore, to assume that all carburizers are equally efficient in their rate of penetration at any one tempera-

ture, whether that heat is 816° C. (1500° Fahr.) or 927° C. (1700° Fahr.).

One point necessary in case-hardening is absolute control over the carburizing temperatures, especially if the work is to be subsequently heat treated. Under such conditions the carburizing heats must be carried as close to the critical range of the steel as possible, and yet give a satisfactory case. If this were not essential carburizing temperatures could be carried to 1038° C. (1900° Fahr.), and even above and the time materially shortened.

The short heats are not the object, as longer and lower ones are given to prevent overheating the steel. The effect of high temperature on steel is a coarse granular structure which is refined only with the greatest difficulty. This is especially true on case-hardened work, as it is difficult to refine the core, and the high heat required for this renders the high carbon case exceedingly weak and brittle, with a tendency to chip.

Case-hardening does not improve the quality of the steel under the most favorable conditions, and the hardener knows it is better to never overheat the metal than try to restore an overheated condition.

To prevent this overheating, therefore, expensive installations of pyrometers are used in connection with the furnaces, and much care is taken that no variations in the carburizing temperatures occur.

There are carburizing materials on the market whose heats cannot be controlled by pyrometers, due to internal combustion occurring in the pots which raise the heat of the mixture above that indicated by the millivoltmeter.

The following experiment was conducted to determine internal heat of carburizing materials, together with their thermal conductivity:

A round box, 8 inches in diameter, filled with the mixture was submerged in a molten salt bath to one inch of the top of the pot. Two thermocouples were used calibrated with each other. One of these was placed in the molten bath and the other in the pot through a hole in

the center of the lid, which was afterwards carefully luted with clay.

After giving the bath sufficient time to thoroughly heat the contents, readings were taken. The temperature of
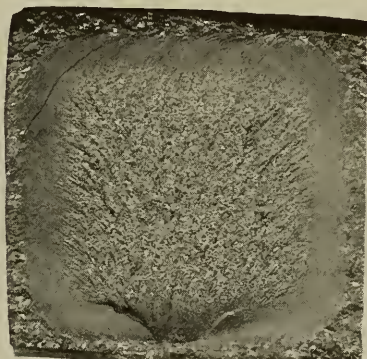

FIG. 33.
Coarse crystallization of case, or "freckled corners."

the molten salts registered 927° C. (1700° Fahr.), and the temperature of the carbonizing material was 1008° C. (1846° Fahr.), or 146° Fahr. higher than the applied heat.

The results of this test indicate plainly that a combustion was occurring in the pot which raised the temperature higher than that indicated on the instruments.

Fig. 33 represents a piece of steel carburized with a carburizing material of such nature. The coarse crystallization of the outer surface of the case which was not refined by a double heat treating is plainly shown. This coarse crystallization of the case is a detriment, as it causes brittleness and chipping of the case.

The rapidity with which a mixture will transmit heat depends largely on its density. Material that is finely powdered will not heat as rapidly as material which is coarse. Material that is porous will convey heat more rapidly than material that is solid, due to free circulation of heated gases inside the pot.
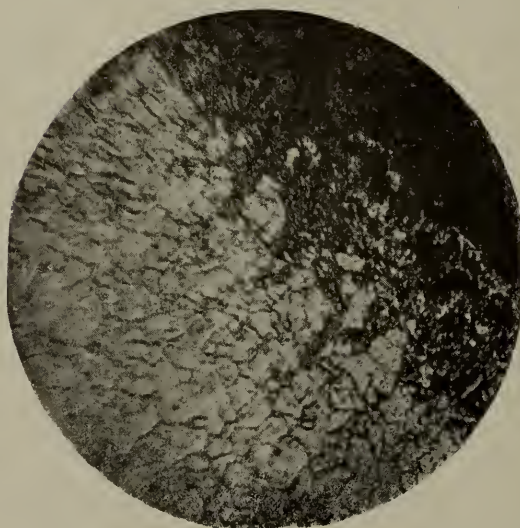
Fig. 34.
Surface decarburization.
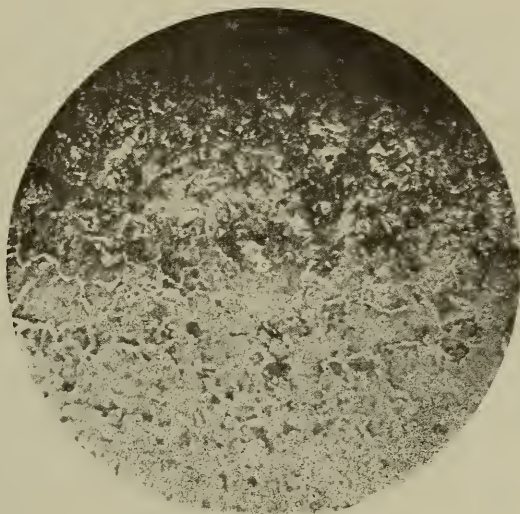

Fig. 35.
Surface decarburization.
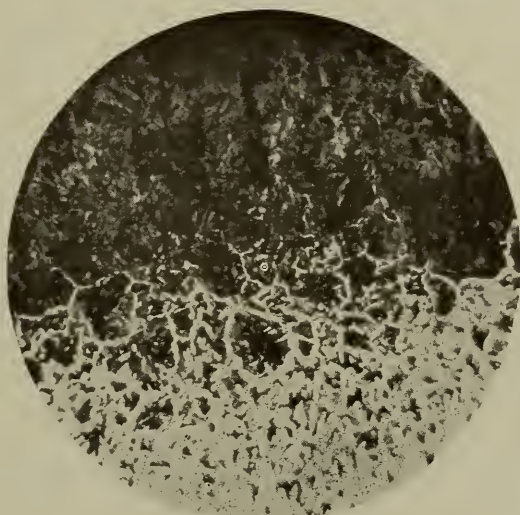
FIG. 36.
Uneven penetration.

FIG. 37.
Uneven penetration.

However, it does not follow that coarse and porous material is more efficient in its penetrating power on the steel than the solid and powdered material.

The value of a carburizing agent also depends on the kind of gases developed by the heat applied.

Some materials give off oxidizing gases, which oxidize the carburized work and result in that condition known as surface decarburization.

We have known of several instances where all the steel carburized in one heat would not harden by quenching, even after the carburizing operation was repeated, yet the broken part showed a good depth of case. Cuts were taken from the outer layer, and upon analysis showed a surface decarburization to a depth of .008 of an inch and a carbon content of .56 per cent. The second cut of .01 inch gave a carbon content of .86 per cent. Figs. 34 and 35 indicate a decarburized condition very plainly.

Usually decarburization occurs only with a weak carburizer and with low carburizing temperatures.

Surface decarburization never occurs when a reducing atmosphere is maintained by the presence of hydro-carbon gases. This point is mentioned because the materials, such as bone, etc., showing slow heat conduction, are rich in hydro-carbons, while in the materials with the greatest thermal conductivity the hydro-carbons are entirely lacking.

All carburizing agents have one detrimental feature or more. One compound may be dusty, and the fumes poisonous to the men doing the packing, while another may exhaust itself quickly and therefore be uneconomical.

In justice to the manufacturers of these materials it may be stated that each mixture is suitable for certain classes of work.

The compounds unsuitable for a clash gear in an automobile transmission may be entirely satisfactory for the carburizing of ball and roller bearings.

Materials and compounds are often poorly mixed, so that they are not homogeneous, with the result that work is penetrated unevenly, as shown in Figs. 36 and 37.

The presence of free Cementite in quantity is due either to too high a temperature in carburizing or to the character of the carburizing compound.

It gives rise to cracks and brittleness, and, further, brittleness is not limited to the case, but extends to and through the core.

This is a cause of "freckled corners" and may be detected by the coarse fracture of a broken section.

CHAPTER XII

HEAT TREATMENT AFTER CARBURIZING

For some work after carburizing the box is emptied hot upon a sieve to separate the work from the compound and the pieces immediately quenched. This practice does not give the maximum strength and toughness.

It is more advisable to allow the work to cool slowly in the pot, and when cold to remove it from the box, place it upon the floor of the furnace, heat to the hardening temperature and then quench. This will give a good case and a tough core, but in order to obtain a hard, refined case with a maximum strength and toughness, the work is heated to a temperature sufficiently high to refine the core and quenched, preferably in oil to avoid checking or cracking the case, and then heated again to the hardening temperature of the case and quenched in water.

The object of the double quenching operation is to give the toughest possible core and the finest crystalline case, and a graduation of case into the core.

The refining temperatures vary with the composition of the steel, and it is advisable to consult the specifications of the Society of Automotive Engineers as mentioned later.

A carbon steel of 10- to 15-point carbon, carburized between the temperatures of 843° C. to 871° C. (1550° Fahr. to 1600° Fahr.), and cooled in the pot and reheated to the hardening temperature of the case and quenched will produce a tough core and fine, hard, compact case. The temperature in this instance is not high enough to coarsen the grain of the core. When carburizing at 954° C. (1750° Fahr.), the temperature

is above the critical range and the grain structure is coarsened, but can be broken up by a double heat treatment to a fairly fine grain.

If strength and resistance to shock are of no importance and where surface hardness is the only requirement, pieces may be quenched directly from the carburizing boxes. The prolonged heating at the high carburizing temperature causes the steel to develop an exceedingly coarse grain, which, by this method of treatment, is retained in the finished product.

Furthermore, during the quenching operation the hot compound is exposed to the air and considerable is lost by its combustion. Common practice, where time and cost permits, is to allow the work to cool in the boxes before removing and heat treating.

Although where time does not permit the work to cool in the pots some concerns are quenching their work directly from a carburizing temperature of 871° C. to 899° C. (1600° Fahr. to 1650° Fahr.), and then reheating to the hardening point of the case and quenching. This first quenching should be done in a good quenching oil for the reason above noted.

CHAPTER XIII

THE HARDENING OF STEEL

Steel in the Austenite stage, on cooling, reverts with greatest rapidity into the Martensite form, with an attendant increase in hardness and assumes a maximum volume. The increase of carbon and the presence of chrome, nickel, manganese, etc., retards this transformation rate. (Twenty-five per cent. nickel preserves Austenite at atmospheric temperature.)

To secure maximum hardness, the steel must be quenched with utmost rapidity in the coldest solution and most efficient conductor of heat. The resulting hardness varies directly with the efficiency of the bath as a conductor of heat, or rather as an abstractor of heat, and is directly a function of the time required to cool the steel to atmospheric temperature.

Without the presence of a retarding alloy, chrome, for instance, it is difficult to commercially secure a Martensitic structure regularly, and when employing simple carbon steels the resultant structure is most likely to be troostite or sorbite, which are softer structures.

These things bring up some practical points in the quenching of steel. The careful operator may first adopt a furnace of the open-fired type, that heats as evenly as possible, and arrange it so that his work shall not be touched by flame or drafts, but for quantity production of fine tools, will doubtless install bath furnaces for the final heating before quenching with preheating furnaces nearby. He will, of necessity, adopt a pyrometer and keep it in order, for no eye is so trained that it can observe the niceties of temperature control required in fine and uniform hardening. Most important of all, he

will operate his furnace so that the temperature of the
heating space never exceeds by more than about 25°
Fahr. his desired quenching temperature, and even though
this practice is slower he will be repaid by the uniformity
of his product.

Having provided means of even heating, so as to do
away with cracking and warping as far as possible, he
will secure a steel giving him the widest practicable range
of control, the uniformity and nature of output consid-
ered. The furnace, pyrometers and steel at hand, he
will then select a quenching medium, oil for relatively soft
work and intricate shapes, water for harder and so on,
minding all the time the fact that the temperature of his
bath and its constancy of composition are important fac-
tors in making a good product.

The care of the operator does not end here, for he
knows that as uneven heating causes a distortion of
the work or rupture, so also will uneven quenching. If
a ring of high carbon steel is quenched with its axis
horizontal, so that one side turns to Martensite, while
the other is still Austenite, the rapid increase of volume
on the Martensite (cool) side will warp the piece five
times as much out of round as if he had quenched it with
the axis vertical. Then, again, if Martensite is aimed for,
room for expansion must be allowed; this is greater in
unalloyed than in some alloyed steels. Even if he uses
a hardening fixture he will see that the work hits the
water in a vertical position to prevent warping.

Quenching should be done on an ascending heat to
reduce the scale and the fire should not be an oxidizing
one.

The treatment must be adapted to the steel used and
multiple treatments when within the critical range can
only refine the structure.

Low carbon steel or the soft backing of carburized steel,
generally below .20 per cent. carbon, is only refined by
heating to Ac3 for that steel 830° C. to 871° C. (1525°
Fahr. to 1600° Fahr.), and then uniformly cooling or

quenching. The case, however, represents a different steel, carrying possibly .80 to 1.30 per cent. carbon; but as this has been obtained at 900° C. to 982° C. (1650° Fahr. to 1800° Fahr.), the grain, already coarse, is slightly refined at 830° C. (1525° Fahr.), but still too coarse. This will be refined without affecting the size of grain of the core (see page 8, Fig 8) by quenching from Ac3 for .80 to 1.10 per cent. carbon steel, or about 760° C. (1400° Fahr.) and the resulting composite structure is the finest the steel is capable of assuming.

In quenching tools care will be necessary to have no sharp line of demarcation between the hardened and softer unquenched sections.

Pyrometers are necessary in hardening high-speed steel at 1148° C. (2100 Fahr.) or above.

In a general way the hardening temperatures are dependent only upon the carbon content, and alloys in the percentage usually contained in commercial tool steels do not materially affect the hardening temperatures, except in high speed steel.

HARDENING TEMPERATURES FOR STEEL OF VARIOUS RANGES OF CARBON CONTENT.

Up to .20% carbon   use 871° to 899° C. (1600° to 1650° F.)
From .20% to .35% C. use 843° to 871° C. (1550° to 1600° F.)
From .35% to .50% C. use 815° to 843° C. (1500° to 1550° F.)
From .50% to .70% C. use 787° to 815° C. (1450° to 1500° F.)
From .70% to .90% C. use 760° to 787° C. (1400° to 1450° F.)
      .90% C. or over use 732° to 760° C. (1350° to 1400° F.)

In order to give a hardening temperature for any definite steel, it would be necessary to know its composition.

The increase in hardness in the different grades of steel is governed by the carbon content, as well as the rate of cooling. The rate of cooling in turn is dependent on the size of the hardened piece of steel, as well as the nature of the quenching medium.

Whatever the quenching medium, whether brine, water or oil, its temperature should be kept low enough to pre-

vent adhesion of vapor bubbles to the quenched steel. In
the selection of oils for the operation particular care
should be taken to select one of uniform quenching speed,
one which will not give off large amounts of gaseous
vapors at comparatively low temperatures, and one which
will not oxidize or thicken on continued use.

From the above it is obvious that the hardening of steel
consists in preventing the formation of soft Pearlite, and
causing the formation and retention of the hard constitu-
ent called Martensite.

This hardening process, however, has its limitations
when pieces of large cross sections are treated. It can
readily be seen that the inside of a comparatively large
piece will not cool as rapidly on quenching as the outside;
hence, the hardening effect is diminished and often
eliminated.

It is always better to harden work that has been pre-
viously annealed, even tools and holder tools, because the
working or forging strains liberated in the change from
Pearlite to Martensite and Austenite may seriously warp
or crack the steel; if not in the fire, this cracking may
take place some time later in use. Thus, mineral oils
which consist of hydrocarbon compounds having different
points of volatilization are quite unsuitable.

CHAPTER XIV

DRAWING OR TEMPERING

We have mentioned the eagerness exhibited by the Austenite structure to transform itself into the original Pearlite through the Martensite, Troostite, Sorbite stages. It is the function of the quenching bath to trap the desired structure. If the quenching has proceeded with sufficient rapidity the steel retains the Martensite stage, but while here we have the greatest volume and hardness; we also have the greatest brittleness. This is relieved by the process of drawing, or tempering.

It is known that in hardened steel, when heated to 200° C. to 400° C. (392° Fahr. to 752° Fahr.), another very slight temperature arrest occurs. This point is called Arc. At the lower temperature the Martensite of the hardened steel begins to change to the softer Troostite; then to Sorbite; then at the higher temperature to soft Pearlite again without attendant increase in grain size.

Fortunately, such low temperatures (about 200° C. or 400° Fahr.) are controlled much more readily than the initial hardening heat, so that in this way the proper structure is readily obtained, a thing almost impossible to do at the original quenching.

The increase in ductility and softening, however, is proportional to the temperature used in the drawing operation. For instance, heating hardened steel to a temperature of 134° C. (275° Fahr.), which is the temperature at which drawing begins, would have very little effect. The changes become more noticeable with increased temperature until the critical temperature is reached, when all the results obtained by the hardening

operation are eliminated and the steel is in the same con-
dition as it was previous to the hardening.

The time of the drawing operation is largely depend-
ent upon the size of the pieces, as well as the temperature.
In other words, the same results can be obtained by draw-
ing at a slightly lower temperature for a longer period of
time, as at a higher temperature for a shorter period
of time.

Ordinarily this operation is carried on in heated oil or
molten salt or lead-drawing furnaces. However, the old
method of open furnace drawing for colors is still used
for drawing the temper in tools extensively. The former
tends to give the more accurate and uniform results, as
they afford a means of more uniform heating and a better
regulation of temperature. The selection of temperature
and time for each individual type of parts can only be
worked out by repeated trials until the desired results
are obtained. When drawing by color it should be borne
in mind, however, that results will vary with carbon
content and condition of the steel. For instance, a piece
of 1 per cent. (100 point) carbon steel will blue quicker
than a .50 per cent. (50 point) carbon steel, also a piece
of hard steel of any carbon content will blue quicker
than soft steel at the same heat.

7

CHAPTER XV

FURNACES FOR CASE-HARDENING

In building or constructing a furnace for case-hardening the size of the work to be hardened should be the first consideration. It is far better to use a small furnace with a small box whenever possible. If the work varies in size, different sizes of furnaces may be used. Small furnaces require less fuel and small work must be placed in small boxes, as otherwise the pieces packed near the sides will be overheated, while those in the center will not reach the required temperature.

Thick walls should be used to retain the heat. These walls should be supported by a substantial concrete foundation, so that they will retain their position and shape, even when subjected to a high heat. Sufficiently large flues should be provided to carry away the smoke and gases.

The furnace should also be so constructed that as much as possible of the heat of the combustion gases may be extracted before they are discharged. The flues and all parts of the furnace should be easily accessible, and a door, the full width of the oven, should be provided, so that the tiles can be taken out and the flues cleaned. A pressure blower, with a light oil, should be used with all the pipes accessible and placed, preferably above the furnace. If, however, they are placed below ground they should be arranged in compartments which can be easily reached if repairs are required.

The blower pipes should be run through the furnace so as to preheat the air used; if cold air is used directly it will reduce the heat in the furnace. The furnace fronts should be made in several parts to prevent cracking, with
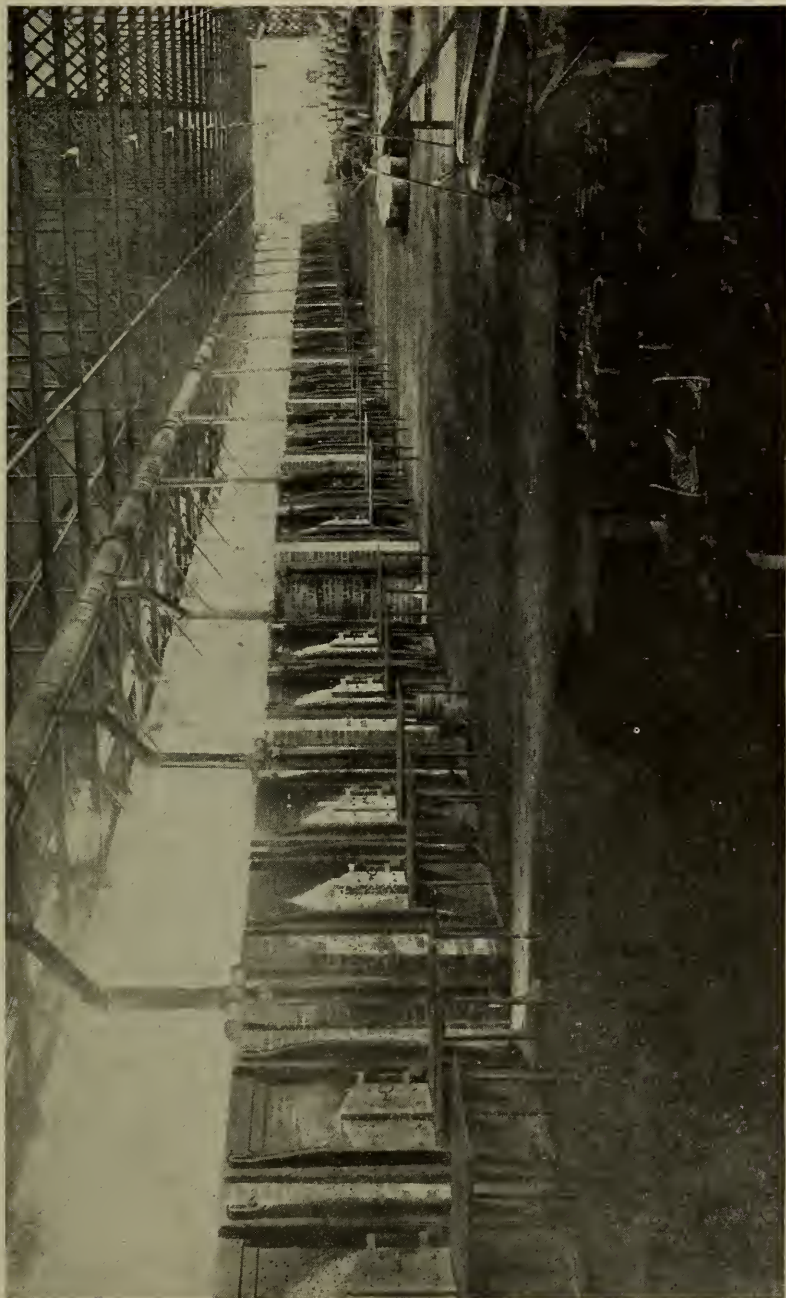
Fig. 38.

Carburizing furnaces at New Departure Mfg. Co., Bristol, Conn.
Arrangement in pairs to economize heating surfaces.

the door properly balanced and lined. A shelf should be provided, projecting at the front, for holding the boxes when they are taken out or put into the furnace. The smokestack should be made of sufficient height to produce a good draft.

FURNACES

In a carburizing furnace, it is perfectly satisfactory to have the flames enter the work chamber, in fact, an under-fired carburizing furnace does not stand up well. In an under-fired furnace such an intense heat is generated under the hearth that the hearth bricks are destroyed. The roof should be arched and the heating flames should enter on a tangent with the arch. It is also important that the arch and burner openings should be of sufficient height so that no flames will impinge directly against the pots.

It is always well to operate furnaces under slight pressure (controlled by dampers), and with a rich atmosphere or flame.

By the use of insulating brick in furnace construction heat losses by radiation are cut down. The wall thickness is not increased and the surrounding room is kept much cooler.

Economy of radiation is effected by erecting in batteries, which in the case of two furnaces, saves two radiation walls. (Fig. 38.)

The furnace should not be heated too quickly, as this is apt to crack the brickwork. The cooling should also be done gradually. After the work has been taken out and the heat shut off for the day, all the dampers should be closed to hold the heat. In this way the furnace will cool slowly and crackings or bulging out of shape will be prevented. In addition, it will be easier to heat the furnace the next morning, as it will have retained some of the heat.
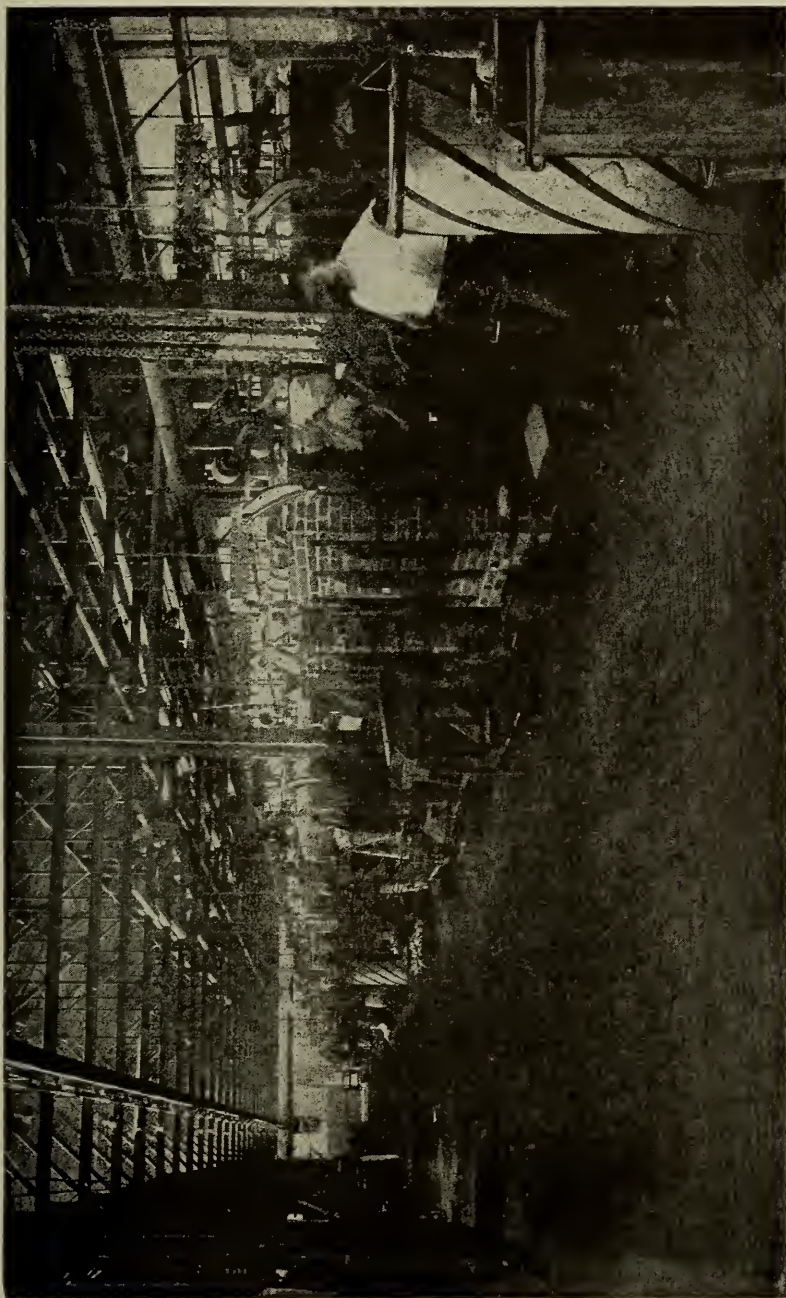
Fig. 39.

Hardening furnaces at New Departure Mfg. Co., Bristol, Conn.

Fig. 40.

Heat Treating furnaces at New Departure Mfg. Co., Bristol, Conn.

When work is to be annealed, it should be placed in the furnace after the work to be hardened has been removed, and then the furnace brought to the proper heat.

The material to be annealed can remain in the furnace until the next morning with the furnace closed and the burners turned off.

The same general construction and operation applies to hardening furnaces of the muffle or semi-muffle type; however it is better on account of oxidation and scaling by combustion gases to underfire.

For comfort of operation and best light conditions furnaces should be placed at right angles to window side of room.   (Figs. 39 and 40.)

CHAPTER XVI

HEATING

The flame should be neutral or slightly rich in gas. This will prevent scaling when heating for forging purposes, and surface decarbonization in annealing and heat treating.

With a muffle furnace, of course, this precaution does not apply. All dies and tools of very fine edge should be heated in a muffle furnace or packed in charcoal when heating for hardening. This method will give the hardest possible surface with the least possible oxidation.

Great care should be exercised in the time required to bring the object to the right temperature. Heating should never be rapid; the final approach to the correct temperature should be slow and uniform.

The location of the pyrometer fire ends should be far from the live action of the flame, but should be placed either in the back or side of the furnace below the level of the arch or flue, where it will record the actual temperature of the furnace.

Fire ends may be protected with steel or porcelain pipe, but it is advisable to use nickel chrome alloy tubes, as the carbon steel tubes oxidize very rapidly and the porcelain tubes are very brittle and easily broken.

It is also advisable to have the fire ends loose at all times, so that when the protective case breaks the couple is less liable to be damaged and can be placed back in the furnace with a new case or pipe without calibration.

A portable pyrometer should be used to check up heats frequently, as fire ends are liable to vary from time to time.

CHAPTER XVII

FUELS

Gas, oil and coal are the fuels used for heating, although electricity is used to some extent with great advantage. The first cost is, however, great, and in some localities the power cost makes it prohibitive. Oil is probably the most used. Coal is used in some districts on account of its low cost, but due to the difficulty of heat regulation and to the expense and annoyance of handling the ashes, etc., it is fast going out of general use for heat treating.

It will be found cheaper when running heat treating furnaces nine or ten hours a day to keep them at a low heat during the night. Tests show that less fuel is burned this way than by shutting off the heat during the night, lighting in the morning, and forcing the heat. Also it eliminates the continual expansion and contraction that breaks a furnace down.

CHAPTER XVIII

QUENCHING

The size of quenching tanks required for any particular class of work will depend upon the size of the pieces to be treated.

It is advisable to have tanks of large capacity for use in quenching large pieces of steel.

After the critical point of the various steels in use has been determined, the subject of next importance is the means of obtaining the proper hardness for the particular purpose.

When a piece of high carbon steel is heated through the critical range the carbon passes into the hardening form, and is retained in that form by proper cooling or quenching. Therefore, it is desirable to determine the speed at which the various liquids will cool the piece of steel and the uniformity in rate of quenching speed of the quenching mediums.

Except in special cases, very high-carbon steels should not be quenched in water. Oil should invariably be used. Steel below 90-point carbon may be quenched in water.

It is advisable to quench thin pieces in oil regardless of their carbon content. A piece of steel should be quenched in such a manner as to cause the least distortion. Where thick and heavy masses of metal are adjacent to thinner and smaller masses the hardener will have to use his judgment as to the best method of quenching. It is generally customary to quench the piece in such a way that the heavier parts come in contact with the quenching medium before the thinner parts.

The selection of the quenching medium is at all times important.

The quenching mediums used most extensively are water, brine water and oil.

PIPES THROUGH WHICH
COLD WATER RUNS

OUTLET TO COOLING TANK

PIPE CONVEYING OIL TO QUENCHING TANK
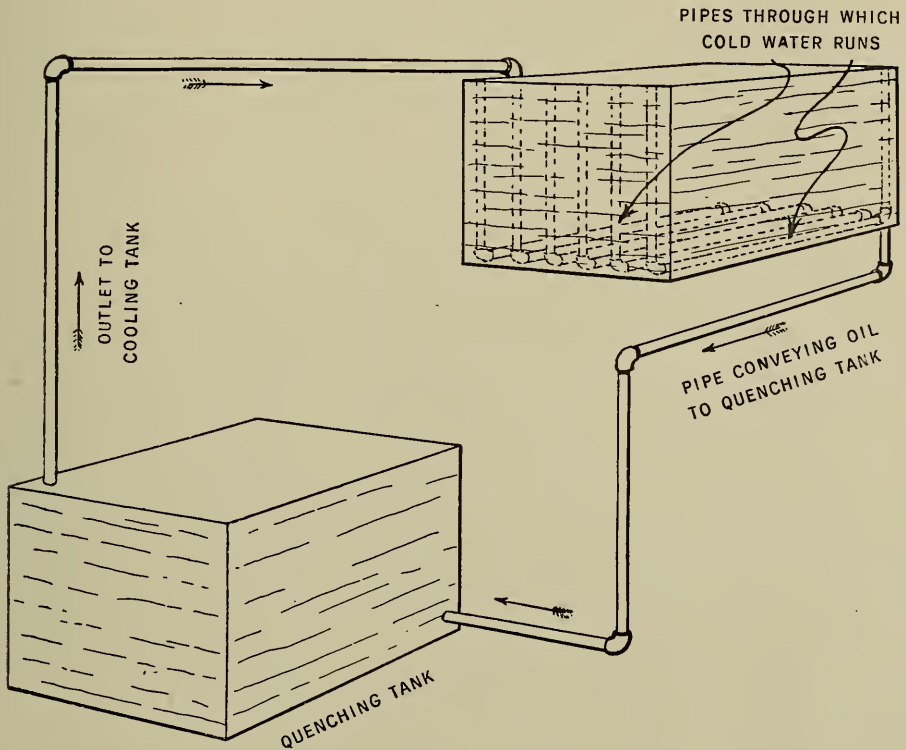
QUENCHING TANK

Fig. 41.

Diagram showing Oil Quenching Tank and Cooling Tank fitted with cold-water coils.

All hardening baths should be constructed with a view to keeping the temperatures of the bath constant at all times.

Where water is used a slight circulation is necessary to keep the water from becoming stagnant, also for cooling purposes. Brine hardening is practiced very little and when done a small tank of brine is usually set in another tank of running water. For oil hardening, if the quantity of the work is small, the tank may also be set in a tank of circulating water. Where large amounts of work are

oil quenched, it is found necessary to cool the oil. This is done in four ways. An ammonia refrigerator machine where either the oil is circulated or cold brine is circulated in pipes through the oil. Second, circulating cold water through the oil tank or the oil through a cold water tank. (See Fig. 41.) Third, by flowing the oil over thin metal surfaces, exposing to the cooling effect of air; and, fourth, by bubbling of air through the oil. These last two in most oils are liable to cause gumming and oxidation. Also in the case of compressed air if the air comes in contact with the work while being quenched it is liable to cause soft spots. Where conditions permit, the ammonia refrigerating process is by far the most satisfactory.

Fresh water in all parts of the country varies slightly from hard to soft water, depending upon the location.

Brine, a mixture of water and common salt, is used in circulating systems or a small tank. Its use imparts greater hardness to steel than water, has a tendency to loosen the scale of the pieces when quenched and thus lessens the possibilities of soft spots.

Oil for quenching should be one that possesses the greatest quenching speed. The oil should not decompose on continued use, nor absorb oxygen from the air and thicken up; it should not undergo a fractional distillation, light ends going off and heavy ends remaining behind, and should not vary in its quenching speed.

Water covered with a few inches of oil is used where the piece should be exceedingly hard, but quenching directly in water would probably cause hardening cracks. The shock in quenching is not as severe as in the case of water and the steel obtains a hardness almost as great as that obtained from water. A quenching medium of this nature is kept cool by means of a water jacket.

In order to successfully harden, one must study the various parts, their design and hardness desired. With the above quenching mediums a wide range of hardness can be secured and any condition satisfied if the bath is modified to suit the purpose.

CHAPTER XIX

MISCELLANEOUS HARDENING METHODS

Heating in Lead

Heating in lead is used extensively where only a slight variation in temperature is permissible. Lead has its disadvantages in that it is so dense as to necessitate holding down the pieces in the lead by some mechanical means. The lead should be as pure as possible and especially free from sulphur. Trouble is sometimes experienced by the lead sticking to the work. This can be avoided by dipping the articles in a solution of cyanide of potassium and water—about one pound of the powdered cyanide to one gallon of boiling water. This should be used cold and the articles permitted to dry before placing in the lead bath. The pieces should be left in the lead only long enough to heat them through. The pieces can be quenched in oil, water or brine, as preferred.

To clean a lead pot it is advisable to add dry, common salt and stir thoroughly with the molten lead. All dirt and foreign matter will rise to the surface, which can be skimmed off with ease.

Heating in Salt

There is considerable difference of opinion regarding the method of heating in salt for hardening purposes. Barium chloride has been used quite extensively, and seems to work perfectly clean at first; but after having been used for some time it begins to pit the steel, which is probably due to the oxide dissolved in the metal salts. If the barium chloride is replaced it then works satis-

factorily again. As long as this constant replacement goes
on good results are obtained.

There are other salts that seem to give satisfactory
results. One of the large steel plants uses a mixture of
calcium chloride and sodium chloride; about three parts
of the former to one part of the latter. This combination
melts at about 482° C. (900° Fahr.), and so is low enough
to prevent the cooling effect of the steel from solidifying
the bath. One advantage of the salt bath is that no bad
results come from the material of the bath adhering to
the object. When the latter is quenched the salt is
solidified and cracks off.

A mixture may be used consisting of calcium chloride
or common salt and soda ash, or sal soda, in the propor-
tion of one part of salt to two parts of soda ash if the
latter be dry, or four parts of sal soda crystals. This
mixture melts at 615° C., or 1140° Fahr., and may be
used either by itself or as a covering on the lead bath.
This will prevent oxidation of the lead and the steel, and
the film formed on the surface of the steel prevents
oxidation while it is being transported from the heating
bath to the quenching bath, and assists in hardening, since
the quenching bath will take hold of the clean surface
quicker than an oxidized surface.

Heating in Cyanide

Cyanide of potassium is also used as a reheating
medium.

It prevents scaling and soft spots.

It has a tendency to add an additional percentage of
carbon to the outside surface of pieces when used as a
reheating medium.

Warping

Warping may be caused by several factors, the two
most important of which are: First, not having the steel
in a proper condition of repose before it is hardened, and,

second, not putting the piece in the quenching bath properly. As any operation of working steel is liable to set up internal strains it is always best after rolling, forging or machining steel to thoroughly anneal the piece before hardening it. This allows the piece to assume its natural state of repose. In the machining operation the roughing cuts should be taken off, the piece annealed, then the finishing cut should be given it and the piece hardened. This would also make the steel easier to machine, as the metal is more uniform and in its softest state.

There are several rules that can be followed in hardening a piece of steel to prevent warping, and these rules always assume that the piece has been properly annealed before starting the hardening operations.

First—A piece should never be thrown into the bath, because in lying on the bottom it is apt to cool faster on one side than the other, and thus cause warping.

Second—The piece should be agitated in the bath to destroy the coating of vapor which might prevent its cooling rapidly, and also to allow the bath to convey its acquired heat to the atmosphere.

Third—Work should be quenched in the direction of its principal axis of symmetry, so that the liquid will cover the greatest possible surface at the instant of quenching. A gear wheel should be plunged perpendicular to its plane, and a shaft vertically.

Local Carburizing

It is often desired to carburize only in certain places on the steel in question. There are several ways by which this may be done. First, by Japanning the part desired to be carburized and then copper-plating. The copper plate will prevent the penetration of the carbon. The Japan prevents copper from plating on the place where it is desired to carburize and will allow the carbon to pass through and into the steel. Second, by protecting the part not desired to be carburized by clay or a paint of water glass and kaolin. Third, by carburizing all

over, allowing enough stock at parts desired soft so that the carburized area may be machined off.   We are indebted to Mr. Frank Kaiser, Metallurgist for the Sullivan Machinery Co., Claremont, N. H., for the following:

Selective Hardening of Carburized Parts and Machining After Hardening

"Occasionally a part is so designed that a portion of it is threaded and it is essential the threads be true and soft; the remainder of the part requiring hardness for wear.   As a rule when a threaded part is carburized and hardened, it is warped and thrown out of centre with the ground surfaces of the rest of the piece.

"To overcome this, the following method has been successful, although more time is required.

"The part is machined for carburizing, leaving about ¼ inch of stock on section to be threaded.   After carburizing and cooling in the pot, this ¼ inch is turned to within 1/64 inch of size.   The part is then hardened by double treating, after which the hardened surfaces are ground.   The end or section to be threaded is then turned to size (the remaining 1/64 inch), true to the ground surfaces, and then threaded.   When this ¼ inch is turned off the carburized zone is entirely machined off, leaving the soft core, and with careful selection of steel and control of treatment, there is no difficulty in the final machining operations.

"Summarizing the operations they are as follows:

"First—Machine for carburizing, leaving ¼ inch of stock on section to be threaded.

"Second—Carburize at 899° C. (1650° Fahr.) for depth of case desired, and cool in pot.

"Third—Turn off all but 1/64 inch of the ¼ inch stock left on section to be threaded.

"Fourth—Heat to 815 to 871° C. (1550-1600° Fahr.), quench in water or oil.   Reheat to 760 to 780° C. (1400-1440° Fahr.), quench in water or oil.

"Fifth—Grind hardened surfaces.

"Sixth—Turn off remaining 1/64 inch true to ground surfaces.

"Seventh—Thread.

It is advisable to use .10 to .20 carbon steel for this class of work.

Steel containing high carbon and high manganese is difficult to machine after heat treatment.

STYLE OF BOXES

After selecting the proper carburizing material the next important factor that enters into carburizing is the style of boxes or pots for packing the work to be carburized.
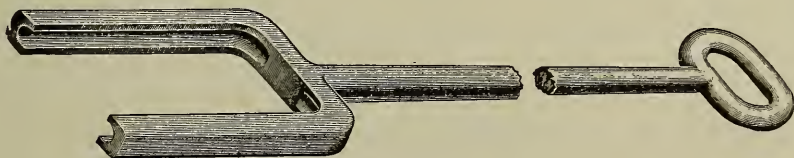
FIG. 42.
Fork for handling small carburizing boxes.

A carburizing pot should be used that withstands the carburizing heat with the least loss in scaling and distortion.

The design or size of a suitable box for all purposes is impossible. The shape of the box should be suited to that of the work.

The walls of the box should not exceed ½ inch nor be less than ¼ inch in thickness. Greater thickness would retard heating and thinner walls would cause scaling and cracking, thus permitting access of air.

To insure more even and rapid heating the boxes should be supplied with legs at the bottom corners.

All unnecessary weight in the boxes should be eliminated so as to save time and fuel in raising the temperature of the furnace after loading.

8

The handling of the boxes when hot can be made easier by use of a suitable fork, as shown in Fig. 42, or a truck for handling heavier boxes, as shown in Fig. 43.
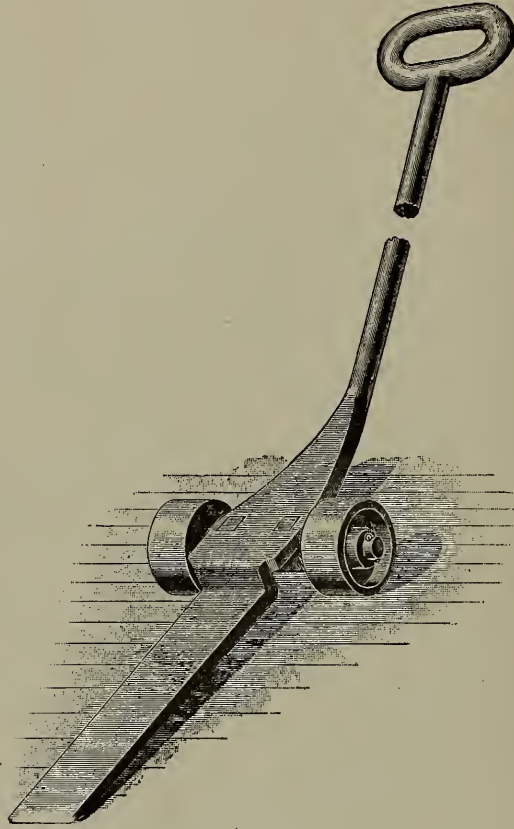
FIG. 43.
Truck for handling heavy carburizing boxes.

Overhead track with trolley and chain hoist can be used in loading and unloading the furnaces.

In motor car work the use of cylinder shaped boxes or pipes, placed in rows in the furnaces, filled with cam shafts and other parts of like nature that require uniform penetration is a common practice.

The study of suitable boxes, pots or pipe for any class of work is time well spent.

Pots with cored center are used for gears, ball and roller bearings and small parts to obtain the most uniform rate of penetration, as shown in Figs. 44 and 45.

The pieces should be packed at least ¼ inch apart and ½ inch from the sides of the carburizing pot. It is advisable to place 1 inch of carburizing material on top of the work under the lid of the pot to allow for shrinkage of the carburizing material.

A lid of the same composition as the carburizing box is placed upon the box and the edges luted with a mixture of 45 per cent. fire clay, 45 per cent. sand and 10 per cent. salt.

The following experiments were conducted to determine the comparative life of various carburizing pots used for carburizing purposes.

The pots were of the same size and thickness of metal, and used at a temperature of 954° C. (1750° Fahr.).

Several pots of the same composition were obtained from various manufacturers.

Material	Life
Malleable Iron	465 hrs.
Malleable Iron	415 "
Alloy Steel, Ni-Cr	517 "
Cast Steel	552 "
Cast Steel	460 "
Puddled Iron	475 "
Wrought Steel	386 "
Cast Iron	169 "
Cast Iron	75 "

There is a Nichrome carburizing pot on the market which is under test to determine its life, and at the time of this writing it has been subjected to a heat of (1750° Fahr.) for 7,000 hours without the loss of weight.

Nichrome pots must last many times as long as malleable iron pots to be more economical; but judging from the life of Nichrome pyrometer protection tubes in carburizing fires these pots should prove more efficient.

These pots should undoubtedly produce more uniform results, inasmuch as the thickness of the sides of the pots

Fig. 44.
Packing pots at the Timken Roller Bearing Co., Canton, Ohio, one of
the largest users of carburizing material in the United States.

Fig. 45.
Unpotting the parts at Timken Roller Bearing Co., Canton, Ohio.

will not diminish as rapidly as the usual iron pots, thereby producing more uniform rate of heating through the same. Although concerns continuously changing the sizes and shapes of their carburizing work could not use these pots economically.

CARBURIZING MATERIALS

All carburizing material should be kept clean. The time is well spent in removing iron scale and fire clay from the carburizing material, as these foreign materials cause soft spots.

The carburizing material should be kept dry, as moisture tends to pit the work and causes soft spots.

Pipes of suitable diameters can be used for carburizing cam-shafts, spindles, etc.

The case of all work to be ground after carburizing should possess a carbon content above 90 point, otherwise it will be ground below the carbon point which gives the hardest possible surface. This is often the cause of soft spots in carburizing.

CALIBRATION OF PYROMETERS

The calibration of a pyrometer may be accomplished readily and accurately without the use of an extensive laboratory equipment. The easiest and most convenient method is that based upon determining the melting point of common table salt (sodium chloride). Chemically pure salt, which is neither expensive nor difficult to procure, should be used where accuracy is desired. The salt is melted in a *clean* crucible of fire clay, iron or nickel, either in a furnace or over a forge fire, and then further heated until a temperature of about 875° to 900° C. (1607° to 1652° Fahr.) is attained. It is essential that this crucible be clean, because a slight mixture of a foreign substance might noticeably lower or raise the melting point.

The thermocouple to be calibrated is then removed from its protecting tube and its *hot* end is immersed in the salt

bath. When this end has reached the temperature of the bath the crucible is removed from the source of heat and allowed to cool, and while cooling readings are taken every ten seconds on the millivoltmeter.

A curve is then plotted by using time and temperature as co-ordinates, and the temperature of the melting point of salt, as indicated by this particular thermocouple, is noted—at the point, namely, where the temperature of the bath remains temporarily constant while the salt is freezing. The length of time during which the temperature is stationary depends on the size of the bath and the rate of cooling, and is not a factor in the calibration. The true melting point of salt is 801° C. (1474° Fahr.), and the needed correction for the instrument under observation can be readily applied.

TABLE NO. III

TEMPERING HEATS OF STEEL, SHOWING COLORS CORRESPONDING TO DIFFERENT TEMPERATURES

215.6° C.	420° F	Very faint yellow
221.1° C.	430° F	Very pale yellow
226.7° C.	440° F	Light yellow
232.2° C.	450° F	Pale straw yellow
237.8° C.	460° F	Deep straw yellow
243.3° C.	470° F	Dark yellow—Straw yellow
248.9° C.	480° F	Deep straw
254.4° C.	490° F	Yellow brown
260.0° C.	500° F	Brown yellow
265.6° C.	510° F	Spotted red brown
271.1° C.	520° F	Brown purple
276.7° C.	530° F	Light purple
282.2° C.	540° F	Full purple
287.8° C.	550° F	Dark purple
293.3° C.	560° F	Full blue
298.9° C.	570° F	Dark blue
315.6° C.	600° F	Very dark blue
400° C.	752° F	Red—Visible in the dark
474° C.	885° F	Red—Visible at twilight
525° C.	975° F	Red—Visible at daylight
581° C.	1077° F	Red—Visible at sunlight
700° C.	1292° F	Dark red
800° C.	1472° F	Dull cherry red
900° C.	1652° F	Cherry red
1000° C.	1832° F	Bright cherry red
1100° C.	2012° F	Orange red
1200° C.	2192° F	Orange yellow
1300° C.	2372° F	Yellow white
1400° C.	2552° F	White; Welding
1500° C.	2732° F	Brilliant white
1600° C.	2912° F	Bluish white

To Reduce the Degrees of a Fahrenheit Thermometer to Those of Reaumer and the Centigrade, and Contrariwise

Fahrenheit to Reaumer.—If above the freezing point.—
Subtract 32 from the number of degrees; multiply the remainder by 4, and divide the product by 9.

Thus, 212°—32°=180°, and 180°×4÷9=80°.

*If below the freezing point.—*Add 32 to the number of degrees; multiply the sum by 4, and divide the product by 9.

Thus, 40°+32°=72°, and 72°×4÷9=—32°.

*Reaumer to Fahrenheit.—*Multiply the number of degrees by 9, and divide the product by 4. Then when they are above the freezing point, add 32 to the quotient, and when they are below, subtract 32.

Thus, 80°×9÷4=180, and 180+32=212°.
" —32°×9÷4=72, and 72—32=40°.

Fahrenheit to Centigrade.—If above the freezing point.—Subtract 32 from the number of degrees; multiply the remainder by 5, and divide the product by 9.

Thus, 212°—32°×5÷9=180×5÷9=100°.

*If below the freezing point.—*Add 32 to the number of degrees; multiply the sum by 5, and divide the product by 9.

Thus, —40°+32×5÷9=72×5÷9=—40°.

*Centigrade to Fahrenheit.—*Multiply the number of degrees by 9, and divide the product by 5. Then, when they are above the freezing point, add 32 to the quotient, and when they are below, subtract 32.

Thus, 100°×9÷5=180, and 180+32=212°.
" —10°×9÷5=18, and 18—32=14°.

*Reaumer to Centigrade.—*Multiply by 5 and divide by 4—thus: 80°×5=400, and 400÷4=100.

*Centigrade to Reaumer.—*Multiply by 4 and divide by 5. Thus 100°×4=400, and 400÷5=80°.

TABLE No. IV

Equivalent of Degrees Centigrade in Fahrenheit

Degrees Centigrade ↓	→0	10	20	30	40	50	60	70	80	90
	Degrees Fahrenheit									
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1004	1022	1040	1057	1076	1094
600	1112	1130	1148	1166	1184	1202	1220	1237	1256	1274
700	1292	1310	1328	1345	1364	1382	1400	1418	1436	1454
800	1472	1490	1508	1526	1544	1562	1580	1598	1616	1634
900	1652	1670	1688	1706	1724	1742	1760	1778	1796	1814
1000	1830	1850	1868	1886	1904	1922	1940	1958	1976	1994
1100	2012	2030	2048	2066	2084	2102	2120	2138	2156	2174
1200	2192	2210	2228	2246	2264	2282	2300	2318	2336	2354
1300	2372	2390	2408	2426	2444	2462	2480	2498	2516	2534
1400	2552	2570	2588	2606	2624	2642	2660	2678	2696	2714
1500	2732	2750	2768	2786	2804	2822	2840	2858	2876	2894
1600	2912	2930	2948	2966	2984	3002	3020	3038	3056	3074
1700	3092	3110	3128	3146	3164	3182	3200	3218	3236	3254
1800	3272	3290	3308	3326	3344	3362	3380	3398	3416	3434
1900	3452	3470	3488	3506	3524	3542	3560	3578	3596	3614
2000	3632	3650	3668	3686	3704	3722	3740	3758	3776	3794

SPECIFICATIONS FOR STEEL
AMERICAN SOCIETY
OF AUTOMOTIVE ENGINEERS

SPECIFICATIONS FOR STEEL

AMERICAN SOCIETY OF AUTOMOTIVE ENGINEERS

SEVENTH REPORT OF IRON AND STEEL DIVISION

SPECIFICATION NUMBERS

A numeral index system has been adopted in the numbering of the metal specifications contained in this report. This system renders it possible to employ specification numerals on shop drawings and blue prints, that are partially descriptive of the quality of material covered by such number. The first figure indicates the class to which the steel belongs; thus *1* indicates a carbon steel, *2* nickel, *3* nickel chromium, etc. In the case of the alloy steels, the second figure generally indicates the approximate percentage of the predominant alloying element. The last two or three figures indicate the average carbon content in "points," or hundredths of one per cent. Thus *2340* indicates a nickel steel with approximately 3 per cent. nickel (3.25%—3.75%) and 0.40 per cent. carbon (.35%—.45%), and *51120* indicates a chromium steel with about 1 per cent. chromium (.90%—1.10%) and 1.20 per cent. carbon (1.10%—1.30%).

The basic numerals for the various qualities of steels herein specified follow:

Carbon steels	1......
Nickel steels	2......
Nickel chromium steels	3......
Chromium steels	5......
Chromium vanadium steels	6......
Silico-manganese steels	9......

The specification for malleable iron has not been assigned a basic numeral in these specifications.

SPECIFICATIONS FOR STEEL

MANUFACTURE AND COMPOSITION

These steels may be of open-hearth, crucible or electric furnace manufacture, and must be homogeneous, sound and free from physical defects, such as pipes, seams, heavy scale or scabs and surface and internal defects visible to the naked eye.

These steels will be purchased on the basis of chemical analysis. The specifications indicate the desired chemical composition. Any shipments not conforming to these specifications after careful check analysis may be rejected.

METHODS FOR SAMPLING

Materials to be sampled shall be considered under three classes, namely:

1. Wire, tubing, sheet and rod metal less than $1\frac{1}{4}$ inch in size shall be sampled across or through the entire section.

2. Forgings or pieces of irregular shape shall be sampled by drilling or cutting at thickest and thinnest sections, or through or across entire section.*

3. Bars and billets or other shapes above $1\frac{1}{4}$ inch thick shall be drilled at half radius, or half-way between center and exterior surfaces.

---

* In drop forgings changes of carbon may be looked for in the outer $\frac{1}{8}$ inch of metal.

CARBON STEELS
SPECIFICATION NO. 1010
Carbon .... .05% to .15% (.10% desired)
Manganese .... .30% to .60% (.45% desired)
Phosphorus, not to exceed.... .045%
*Sulphur, not to exceed.... . .05%

SPECIFICATION NO. 1020
Carbon .... 15% to .25% (.20% desired)
Manganese .... .30% to .60% (.45% desired)
Phosphorus, not to exceed.... .045%
*Sulphur, not to exceed.... . .05%

SPECIFICATION NO. 1025
Carbon .... .20% to .30% (.25% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .045%
*Sulphur, not to exceed...... .05%

SPECIFICATION NO. 1035
Carbon .... .30% to .40% (.35% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .045%
*Sulphur, not to exceed...... .05%

SPECIFICATION NO. 1045
Carbon .... .40% to .50% (.45% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .045%
*Sulphur, not to exceed...... .05%

SPECIFICATION NO. 1095
Carbon .... .90% to 1.05% (.95% desired)
Manganese .... .25% to .50% (.35% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .05%

* See note on page 120.

SCREW STOCK

SPECIFICATION NO. 1114

Carbon .... .08% to .20%
Manganese .... .30% to .80%
Phosphorus, not to exceed.... .12%
*Sulphur .... .06% to .12%

STEEL CASTINGS

SPECIFICATION NO. 1235

Carbon ....As required for physical properties
Phosphorus, not to exceed.... .05%
*Sulphur, not to exceed...... .05%
  Note.—See "Notes and Instructions."

NICKEL STEELS

SPECIFICATION NO. 2315

Carbon .... .10% to .20% (.15% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .05%
Nickel .... 3.25% to 3.75% (3.50% desired)

SPECIFICATION NO. 2320

Carbon .... .15% to .25% (.20% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 3.25% to 3.75% (3.50% desired)

SPECIFICATION NO. 2330

Carbon .... .25% to .35% (.30% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 3.25% to 3.75% (3.50% desired)

  * See note on page 120.

SPECIFICATION NO. 2335

Carbon .... .30% to .40% (.35% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 3.25% to 3.75% (3.50% desired)

SPECIFICATION NO. 2340

Carbon .... .35% to .45% (.40% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 3.25% to 3.75% (3.50% desired)

SPECIFICATION NO. 2345

Carbon .... .40% to .50% (.45% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorous, not to exceed... .04%
*Sulphur, not to exceed....... .045%
Nickel .... 3.25% to 3.75% (3.50% desired)

NICKEL CHROMIUM STEELS

SPECIFICATION NO. 3120

Carbon .... .15% to .25% (.20% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 1.00% to 1.50% (1.25% desired)
Chromium .... .45% to .75%†(.60% desired)

* See note on page 120.

† Another grade of this type of steel is available with chromium content of .15 per cent. to .45 per cent. Its physical properties are somewhat lower than those of the grade with chromium content indicated in specifications Nos. 3120, 3125, 3130, 3135 and 3140.

9

SPECIFICATION NO. 3125

Carbon .... .20% to .30% (.25% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 1.00% to 1.50% (1.25% desired)
Chromium .... .45% to .75%†(.60% desired)

SPECIFICATION NO. 3130

Carbon .... .25% to .35% (.30% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 1.00% to 1.50% (1.25% desired)
Chromium .... .45% to .75%†(.60% desired)

SPECIFICATION NO. 3135

Carbon .... .30% to .40% (.35% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 1.00% to 1 50% (1.25% desired)
Chromium .... .45% to .75%†(.60% desired)

SPECIFICATION NO. 3140

Carbon .... .35% to .45% (.40% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Nickel .... 1.00% to 1.50% (1.25% desired)
Chromium .... .45% to .75%†(.60% desired)

* See note on page 120.
† Another grade of this type of steel is available with chromium content of .15 per cent. to .45 per cent. Its physical properties are somewhat lower than those of the grade with chromium content indicated in specifications Nos. 3120, 3125, 3130, 3135 and 3140.

SPECIFICATION NO. 3220
```
Carbon ..................... .15% to  .25% ( .20% desired)
Manganese ................. .30% to  .60% ( .45% desired)
Phosphorus, not to exceed....         .04%
*Sulphur, not to exceed......         .04%
Nickel .................... 1.50% to 2.00% (1.75% desired)
Chromium ................. .90% to 1.25% (1.10% desired)
```

SPECIFICATION NO. 3230
```
Carbon ..................... .25% to  .35% ( .30% desired)
Manganese ................. .30% to  .60% ( .45% desired)
Phosphorus, not to exceed....         .04%
*Sulphur, not to exceed......         .04%
Nickel .................... 1.50% to 2.00% (1.75% desired)
Chromium ................. .90% to 1.25% (1.10% desired)
```

SPECIFICATION NO. 3240
```
Carbon ..................... .35% to  .45% ( .40% desired)
Manganese ................. .30% to  .60% ( .45% desired)
Phosphorus, not to exceed....         .04%
*Sulphur, not to exceed......         .04%
Nickel .................... 1.50% to 2.00% (1.75% desired)
Chromium ................. .90% to 1.25% (1.10% desired)
```

SPECIFICATION NO. 3250
```
Carbon ..................... .45% to  .55% ( .50% desired)
Manganese ................. .30% to  .60% ( .45% desired)
Phosphorus, not to exceed....         .04%
*Sulphur, not to exceed......         .04%
Nickel .................... 1.50% to 2.00% (1.75% desired)
Chromium ................. .90% to 1.25% (1.10% desired)
```

SPECIFICATION NO. X3315
```
Carbon ..................... .10% to  .20% ( .15% desired)
Manganese ................. .45% to  .75% ( .60% desired)
Phosphorus, not to exceed....         .04%
*Sulphur, not to exceed......         .04%
Nickel .................... 2.75% to 3.25% (3.00% desired)
Chromium ................. .60% to  .95% ( .80% desired)
```

* See note on page 120.

SPECIFICATION NO. X3335

Carbon .... .30% to .40% (.35% desired)
Manganese .... .45% to .75% (.60% desired)
Phosphorus, not to exceed....   .04%
*Sulphur, rot to exceed......   .04%
Nickel .... 2.75% to 3.25% (3.00% desired)
Chromium .... .60% to .95% (.80% desired)

SPECIFICATION NO. X3350

Carbon .... .45% to .55% (.50% desired)
Manganese .... .45% to .75% (.60% desired)
Phosphorus, not to exceed....   .04%
*Sulphur, not to exceed......   .04%
Nickel .... 2.75% to 3.25% (3.00% desired)
Chromium .... .60% to .95% (.80% desired)

SPECIFICATION NO. 3320

Carbon .... .15% to .25% (.20% desired)
Manganese .... .30% to .60% (.45% desired)
Phosphorus, not to exceed....   .04%
*Sulphur, not to exceed......   .04%
Nickel .... 3.25% to 3.75% (3.50% desired)
Chromium .... 1.25% to 1.75% (1.50% desired)

SPECIFICATION NO. 3330

Carbon .... .25% to .35% (.30% desired)
Manganese .... .30% to .60% (.45% desired)
Phosphorus, not to exceed....   .04%
*Sulphur, not to exceed......   .04%
Nickel .... 3.25% to 3.75% (3.50% desired)
Chromium .... 1.25% to 1.75% (1.50% desired)

SPECIFICATION NO. 3340

Carbon .... .35% to .45% (.40% desired)
Manganese .... .30% to .60% (.45% desired)
Phosphorus, not to exceed....   .04%
*Sulphur, not to exceed......   .04%
Nickel .... 3.25% to 3.75% (3.50% desired)
Chromium .... 1.25% to 1.75% (1.50% desired)

* See note on page 120.

CHROMIUM STEELS

SPECIFICATION NO. 5120

Carbon .... .15% to .25% (.20% desired)
Manganese .... †
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Chromium .... .65% to .85% (.75% desired)

SPECIFICATION NO. 5140

Carbon .... .35% to .45% (.40% desired)
Manganese .... †
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Chromium .... .65% to .85% (.75% desired)

SPECIFICATION NO. 5165

Carbon .... .60% to .70% (.65% desired)
Manganese .... †
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .045%
Chromium .... .65% to .85% (.75% desired)

SPECIFICATION NO. 5195

Carbon .... .90% to 1.05% (.95% desired)
Manganese .... .20% to .45% (.35% desired)
Phosphorus, not to exceed.... .03%
*Sulphur, not to exceed...... .03%
Chromium .... .90% to 1.10% (1.00% desired)

SPECIFICATION NO. 51120

Carbon .... 1.10% to 1.30% (1.20% desired)
Manganese .... .20% to .45% (.35% desired)
Phosphorus, not to exceed.... .03%
*Sulphur, not to exceed...... .03%
Chromium .... .90% to 1.10% (1.00% desired)

* See note on page 120.
† Two types of steel are available in this class, viz., one with manganese .25 to .50 per cent. (.35 per cent. desired), and silicon not over .20 per cent.; the other with manganese .60 to .80 per cent. (.70 per cent. desired), and silicon .15 to .50 per cent.

SPECIFICATION NO. 5295

Carbon .... .90% to 1.05% (.95% desired)
Manganese .... .20% to .45% (.35% desired)
Phosphorus, not to exceed.... .03%
*Sulphur, not to exceed...... .03%
Chromium .... 1.10% to 1.30% (1.20% desired)

SPECIFICATION NO. 52120

Carbon .... 1.10% to 1.30% (1.20% desired)
Manganese .... .20% to .45% (.35% desired)
Phosphorus, not to exceed.... .03%
*Sulphur, not to exceed...... .03%
Chromium .... 1.10% to 1.30% (1.20% desired)

CHROMIUM VANADIUM STEELS

SPECIFICATION NO. 6120

Carbon .... .15% to .25% (.20% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

SPECIFICATION NO. 6125

Carbon .... .20% to .30% (.25% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

SPECIFICATION NO. 6130

Carbon .... .25% to .35% (.30% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

* See note on page 120.

SPECIFICATION NO. 6135

Carbon .... .30% to .40% (.35% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

SPECIFICATION NO. 6140

Carbon .... .35% to .45% (.40% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

SPECIFICATION NO. 6145

Carbon .... .40% to .50% (.45% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

SPECIFICATION NO. 6150

Carbon .... .45% to .55% (.50% desired)
Manganese .... .50% to .80% (.65% desired)
Phosphorus, not to exceed.... .04%
*Sulphur, not to exceed...... .04%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

SPECIFICATION NO. 6195

Carbon .... .90% to 1.05% (.95% desired)
Manganese .... .20% to .45% (.35% desired)
Phosphorus, not to exceed.... .03%
*Sulphur, not to exceed...... .03%
Chromium .... .80% to 1.10% (.95% desired)
Vanadium, not less than...... .15% (.18% desired)

* See note on page 120.

SILICO-MANGANESE STEEL

SPECIFICATION NO. 9250

Carbon .... .45% to .55% (.50% desired)
Manganese .... .60% to .80% (.70% desired)
Phosphorus, not to exceed.... .045%†
*Sulphur, not to exceed...... .045%
Silicon .... 1.80% to 2.10% (1.95% desired)

SPECIFICATION NO. 9260

Carbon .... .55% to .65% (.60% desired)
Manganese .... .50% to .70% (.60% desired)
Phosphorus, not to exceed.... .045%†
*Sulphur, not to exceed...... .045%
Silicon .... 1.50% to 1.80% (1.65% desired)

MALLEABLE IRON

Manganese .... .30% to .70%
Phosphorus, not to exceed.... .20%
*Sulphur, not to exceed...... .06%
Silicon, not to exceed........ 1.00%

* Recognizing the wide variance in methods used for the determination of sulphur, the final reference method shall be the gravimetric (aqua regia) method, by oxidation.

† Steel made by the acid process may contain maximum .05 per cent. phosphorus.

REVISED NOTES AND INSTRUCTIONS
REFERRING TO MATERIALS
SPECIFIED

REGARDING NOTES AND INSTRUCTIONS

The notes and instructions following the chemical specifications are not to be considered in any way a part of these specifications. They are added solely for the information of the user of the steels and for the guidance of the purchaser in the selection of proper steels for his different purposes. They should not be incorporated in the specification when ordering steel. This is especially true of the "Physical Characteristics." Where possible, specific data are given on the physical properties which can be expected with the most widely used heat treatments.

REMARKS CONCERNING GENERAL PHYSICAL
PROPERTY DATA

The materials specified in detail as S. A. E. steels include the most important ones available to the builder of automobiles.

The results of physical tests, whether tension tests or otherwise, are largely dependent upon the mass and form of the specimen tested. This is particularly true of heat-treated steels. For the foregoing reason all results of physical tests are comparative, and in order to make the comparison a proper one a uniform test specimen must be used.

The committee therefore decided that recommended practice should be the use of the S. A. E. standard test specimen, this specimen to be treated approximately in its finished form, leaving only sufficient stock for finish grinding after the treatment is completed, say .020 inch on the diameter.

The figures for physical characteristics given for all steels following Specification No. 1045 refer to those obtained on speci-

mens prepared from sections common in automobile use, that is, bars from 1 inch round up to 1½ inches round.

The yield point is under control in two ways—by choice of quenching medium (oil, water or brine), and by varying the final drawing temperature. In the interpretation of the physical characteristic figures it must be remembered that only the minimum figures as to toughness (*i. e.*, reduction and elongation) may be expected with the highest degree of strength (*i. e.*, yield point); and, conversely, that the highest degree of toughness may be expected with the lowest yield point. *This remark applies to all heat-treated steels.* It would be manifestly impossible to obtain the highest percentage of elongation and the highest yield point on the same specimen.

The yield point is specified rather than the elastic limit. The yield point is measured by the drop of the testing machine beam, and furnishes the most ready and widely used measure of the so-called elastic limit; results obtained by this method, however, are generally from 5,000 to 15,000 pounds higher than the true elastic limit where this property is not in excess of 125,000 pounds per square inch. With material having a yield point in excess of 125,000 pounds per square inch the true elastic limit should be obtained by means of an extensometer.

There is little use in giving the physical characteristics of a carbonized steel, inasmuch as any test must be deceptive because of the very high carbon exterior case, which cracks and fails long before the soft and tough interior does. This means that the rupture is fragmental and progressive and misleading.

In addition to the usual physical characteristics the "hardness" tests have been considered, as obtained by means of the Brinell ball test and the Shore scleroscope. The Brinell test recommended by the committee is the use of the 10-millimeter ball and 3,000-kilogram load. It is pointed out, however, that the Brinell test must not be used on soft steels less than ½ inch thick, or on areas small enough to permit the depression to flow toward the edges of the specimen. With hard steels, where the depth of the depression and the flow of metal are less, material as thin as ¼ inch may be so tested. The Brinell test may be fairly made on surfaces that are free from scale and smooth.

The Shore test (scleroscope) must be used only on surfaces that have been carefully polished and freed from all tool marks, file marks or grinding scratches. The test specimen should also be of such mass or be held in such manner as to give the greatest possible freedom from deflection when struck by the hammer.

CARBON STEELS

SPECIFICATION NO. 1010

.10 CARBON STEEL

This is usually known in the trade as soft, basic open-hearth steel. It is a material commonly used for seamless tubing, pressed steel frames, pressed steel brake-drums, sheet steel brake-bands and pressed steel parts of many varieties. It is soft and ductile, and will stand much deformation without cracking .

This steel in a natural or annealed condition has little tenacity, and must not be used where much strength is required. This quality of material is considerably stronger after cold drawing or rolling; that is, its yield point is raised by such working. This is important in view of the fact that many wire and sheet metal parts above mentioned are used in the cold rolled or cold drawn form.

It must not be forgotten that when this steel (so cold worked) is heated, as for bending, brazing, welding or the like, the yield point returns to that characteristic of the annealed material. *This remark also applies to all materials that have an increased yield point produced by cold working.*

This material in a natural or annealed state does not machine freely. It will tear badly in turning, threading and broaching operations. Heat treatment produces but little benefit, and that not in strength but in toughness. It is possible to quench this grade of steel and put it in a condition to machine better than in the annealed state.

The heat treatment which will produce a little stiffness is to quench at 1500° Fahr. in oil or water. No drawing is required.

PHYSICAL CHARACTERISTICS

	Annealed	Cold Rolled or Cold Drawn
Yield point, lbs., per sq. in.	28,000 to 36,000	40,000 to 60,000*
Reduction of area	65-55%	55-45%
Elongation in 2"	40-30%	Unimportant

This steel will case-harden, but is not as suitable for this purpose as Steel 1020, a note on which follows:

SPECIFICATION NO. 1020

.20 CARBON STEEL

This steel is known to the trade as .20 carbon, open-hearth steel, and often as machine steel.

This quality is intended primarily for case-hardening. It forges well and machines well, but should not be considered as screw machine stock. It may therefore be used for a very large variety of forged, machined and case-hardened parts of an automobile where strength is not paramount.

Steel of this quality may also be drawn into tubes and rolled into cold-rolled forms, and, as a matter of fact, makes a better frame than Steel 1010, because of the slightly higher carbon and resulting strength. The increased carbon content has no detrimental effect as far as usage is concerned, and it is only the most difficult of cold-forming operations that cause it to crack during the forming. For automobile parts it may be safely used interchangeably with Steel 1010 as far as cold-pressed shapes are concerned.

Heat treatment of this steel produces but little change as far as strength is concerned, but does cause a desirable refinement of grain after forging, and materially increases the toughness. The following treatment, which will often help the machining qualities, is all that is necessary:

* These high yield points can be obtained only in comparatively light or small sections, either in the sheet or rod form; say one-half inch round or one-quarter inch sheets or flats.

Heat Treatment H

After forging or machining:
1. Heat to 1500°-1600° Fahr.
2. Quench.
3. Reheat to 600°-1200° Fahr. and cool slowly.

Case-hardening is the most important treatment for this quality of steel. The character of the operation must depend upon the importance of the part to be treated, and upon the shape and size. There is a certain group of parts in an automobile which are not called upon to carry much load or withstand any shock. The principal requirement is hardness. Such parts are fairly illustrated by screws and by rod-end pins. The simplest form of case-hardening will suffice, viz.:

Heat Treatment A

After forging or machining:
1. Carbonize at a temperature between 1600° Fahr. and 1750° Fahr. (1650°-1700° Fahr. desired).
2. Cool slowly or quench.
3. Reheat to 1450°-1500° Fahr. and quench.

Another class of parts demands the best treatment (Heat Treatment B), such as gears, steering-wheel pivot-pins, cam-rollers, push-rods and many similar details of an automobile, which, the manufacturer learns by experience, must be not only hard on the exterior surface, but must possess strength as well. The desired treatment is one which first refines and strengthens the interior and uncarbonized metal. This is then followed by a treatment which refines the exterior carbonized or high-carbon metal.

Heat Treatment B

After forging or machining:
1. Carbonize at a temperature between 1600° Fahr. and 1750° Fahr. (1650°-1700° Fahr. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1550°-1625° Fahr.
4. Quench.
5. Reheat to 1400°-1450° Fahr.
6. Quench.

7. Draw in hot oil at a temperature which may vary from
300° Fahr. to 450° Fahr., depending upon the degree
of hardness desired.

In the case of very important parts, the last drawing operation
should be continued from one to three hours to insure the full
benefit of the operation.

The objects of drawing are two-fold: First, and not least im-
portant, is the relieving of all internal strains produced by quench-
ing; second is the decrease in hardness, which is sometimes de-
sirable. The hardness begins to decrease very materially from
350° Fahr. up, and the operation must be controlled as dictated
by experience with any given part.

There are certain very important pieces that demand all of
these operations, but the last drawing operation may be omitted
with a large number. Experience teaches what degree of hard-
ness and toughness combined is necessary for any given part. It
is impossible to lay down a general rule covering all different
uses. If the fundamental principle is well understood there
should be no trouble in developing the treatment to a proper
degree.

Following the foregoing treatment, a fractured part should
show a fine-grained exterior, without any appearance of shiny
crystals. The smaller the crystals the better. The interior may
show a silky, fibrous condition or a fine crystalline condition; but
it must not show a coarse, shiny, crystalline condition.

Physical Characteristics

When cold rolled or cold drawn this steel will have a yield
point of 40,000 to 75,000* pounds per square inch and a reduction
of area from 35 to 30 per cent.

SPECIFICATION NO. 1025

.25 Carbon Steel

This steel is used most widely for frames and for ordinary
drop forgings where moderate ductility is desired but high
strength is not essential. Heat treatment has a moderate effect

* In sections not over one-half inch round or one-quarter inch sheets
or flats.

on the physical properties, but this effect is not nearly so marked as on Steel 1035.

Heat treatment H or D may be used for this quality of steel.

Heat treatment H is the simplest form of heat treatment; the drawing operation (No. 3) must be varied to suit each individual case. If great toughness and little increased strength are desired, the higher drawing temperatures may be used, that is, in the neighborhood of 1100° Fahr. to 1200° Fahr. If much strength is desired and little toughness, the lower temperatures are available. Even the lowest of the temperatures given will produce a quality of steel, after oil quenching, that is very tough—sufficiently tough for many important parts. In fact, with some parts the drawing operation (No. 3) may be entirely omitted.

Results better than obtainable with the above sequence of operations may be obtained by a double treatment, viz.:

HEAT TREATMENT D

After forging or machining:
1. Heat to 1500°-1600° Fahr.
2. Quench.
3. Reheat to 1450°-1500° F.
4. Quench.
5. Reheat to 600°-1200° Fahr. and cool slowly.

This produces a refinement of grain not possible with one treatment, and is resorted to in parts where extremely good qualities are desired.

This quality of steel is not intended for case-hardening, but by careful manipulation it may be so treated. This should be done in emergencies only, rather than as a regular practice, and, if at all, only with the double treatment followed by the drawing operation; that is, the most painstaking form of case-hardening.

SPECIFICATION NO. 1035

.35 CARBON STEEL

This material is sometimes referred to in the trade as .35 carbon machine steel.

It is primarily for use as a structural steel. It forges well, machines well, and responds to heat treatment in the matter of

strength as well as toughness; that is to say, intelligent heat treat-
ment will produce marked increase in the yield point. It may be
used for all forgings such as axles, driving-shafts, steering pivots
and other structural parts. It is the best all-round structural steel
for such use as its strength warrants.

Heat treatment for toughening and strength is of importance
with this steel. The heat treatment must be modified in accord-
ance with the experience of the individual user, to suit the size
of the part treated and the combination of strength and toughness
desired. The steel should be heat-treated in all cases where re-
liability is important.

Machining may precede the following heat treatment, depend-
ing somewhat upon convenience and the character of the treat-
ment. If the highest strength is demanded, a strong quenching
medium must be employed; for example, brine. In such case
the yield point will be correspondingly high and the steel corre-
spondingly hard and difficult to machine. On the other hand, if a
moderately high yield point is all that is desired, an oil quench
will suffice, and machining may follow without any difficulty
whatever.

Heat treatment H, D or E may be used on this quality of steel.
When heat treatment E is applied, machining may follow opera-
tion 2.

Heat Treatment E

After forging or machining:
1. Heat to 1500°-1550° Fahr.
2. Cool slowly.
3. Reheat to 1450°-1500° Fahr.
4. Quench.
5. Reheat to 600°-1200° Fahr. and cool slowly.

SPECIFICATION NO. 1045

.45 Carbon Steel

This material is ordinarily known to the trade as .45 carbon
machine steel. This quality represents a structural steel of greater
strength than Steel 1035. Its uses are more limited, and are con-
fined, in a general way, to such parts as demand a high degree of

strength and a considerable degree of toughness. At the same time, with proper heat treatment the fatigue-resisting (endurance) qualities are very high—higher than with any of the foregoing specifications.

This steel is commonly used for crankshafts, driving-shafts and propeller-shafts. It has also been used for transmission gears, but it is not quite hard enough without case-hardening, and is not tough enough with case-hardening, to make safe transmission gears. It should not be used for case-hardened parts. Other specifications are decidedly better for this purpose.

In a properly annealed condition it machines well—not well enough for screw machine work, but certainly well enough for all-round machine-shop practice. Heat treatment E provides the annealing operation when needed, machining to follow operation 2; this treatment is especially adapted to crankshafts and similar parts. Heat treatment H is also commonly used for this quality of steel.

SPECIFICATION NO. 1095

.95 Carbon Steel

This is a grade of steel used generally for springs. Properly heat-treated, extremely good results are possible.

The hardening and drawing of springs, that is, the heat treatment of them, is, as a rule, in the hands of the springmaker, but in case it is desired to treat, as for small springs, the following is recommended:

Heat Treatment F

After shaping or coiling:
1. Heat to 1425°-1475° Fahr.
2. Quench in oil.
3. Reheat to 400°-900° Fahr., in accordance with degree of temper desired, and cool slowly.

It must be understood that the higher the drawing temperature (Operation 3), the lower will be the yield point of the material. On the other hand, if the material be drawn at too low a temperature it will be brittle. A few practical trials will locate the best temper for any given shape or size.

10

The physical characteristics of heat-treated spring steel are best determined by transverse test. This is because steel as hard as tempered spring steel is very difficult to hold firmly in the jaws of a tensile testing machine. There is more or less slip, and side strains are bound to occur, all of which tends to produce misleading results.

The physical characteristics in the annealed condition may be omitted, inasmuch as this grade of steel is not ordinarily used for structural parts in such condition.

Careful examination of the fracture of the treated material is desirable. After tempering, no suitable spring steel should be coarsely crystalline. It should be finely crystalline, and in some cases will show a partly fibrous fracture.

PHYSICAL CHARACTERISTICS
(Transverse Test)

	Heat Treatment F.
Elastic limit (initial set), lbs. per sq. in......	90,000
	to
	180,000
Reduction of area	Not determined
	in transverse test
Elongation	do

SCREW STOCK

SPECIFICATION NO. 1114

This steel may be made by any process. It is intended for use where high screw machine production is the important factor, strength and toughness being secondary considerations. Its composition and texture are of such nature as to permit the rapid removal of metal and a resulting smoothness of finish.

STEEL CASTINGS

SPECIFICATION NO. 1235

In the following remarks, genuine steel castings, and not malleable iron or complex mixtures often found in the market masquerading under the name of steel, are referred to.

All steel castings should be annealed, and some shapes may be heat-treated to great advantage. Like other castings, steel castings are subject to blow-holes. Consequently they should not be used in the vital parts of an automobile. It is impossible to inspect against blow-holes, and steel castings for axles, crankshafts and steering spindles are used only at great risk. Freedom from blow-holes and proper physical condition are of more importance than the absolute analysis.

On account of the great influence of varying types of foundry practice upon the properties of castings, it has not been found feasible to give a closer specification for chemical composition than that quoted under No. 1235. If it is desired to buy steel castings under precise specifications, the following, based upon the "Specifications for Steel Castings, Class B, Serial Designation A 27-14," of the American Society for Testing Materials, can be used:

I. Manufacture

1. The steel may be made by any process approved by the purchaser. Three grades are recognized: hard, medium and soft.

2. All castings shall be allowed to become cold; they shall then be reheated uniformly to the proper temperature to refine the grain, and allowed to cool uniformly and slowly.

II. Chemical Properties and Tests

3. No casting, on check analysis, shall show over .05 per cent. phosphorus or sulphur. The carbon content shall be suitable for the physical tests and service required.

4. Drillings for analysis shall be so taken as to represent the average composition of the casting.

III. Physical Properties and Tests

5. The finished castings shall conform to the following minimum requirements as to tensile properties:

	Hard	Medium	Soft
Tensile strength, lb. per sq. in....	80,000	70,000	60,000
Yield point, lb. per sq. in.........	36,000	31,500	27,000
Reduction of areas, per cent.....	20	25	30
Elongation in 2 in., per cent.....	15	18	22

6. The test specimen for soft castings shall bend cold through 120 degrees, and for medium castings through 90 degrees, around a 1-inch pin, without cracking on the outside. Hard castings shall not be subject to bent-test requirements.

7. In the case of small or unimportant castings, a test to destruction on three castings from a lot may be substituted for the tension and bend tests. This test shall show the material to be ductile, free from injurious defects, and suitable for the purpose intended. A lot shall consist of all castings from one melt, in the same annealing charge. In case test bars are cast separate, they shall be annealed with the lot they represent, the method of casting such test bars, or of casting test bars attached to castings, to be agreed upon by purchaser and manufacturer.

8. Tension test specimens shall be machined to the standard S. A. E. form; bend test specimens shall be machined to 1 by ½ inch in section, with corners rounded to a radius not over 1/16 inch.

9. One tension and one bend test shall be made from each annealing charge. If more than one melt is represented in an annealing charge, one tension and one bend test shall be made from each melt.

10. If any test specimen shows defective machining or develops flaws, it may be discarded, in which case another specimen may be selected by the manufacturer and the purchaser.

11. A retest shall be allowed if the percentage of elongation is less than that specified or if any part of the fracture is more than ¾ inch from the center of the gauge length as indicated by scribe scratches marked on the specimen before testing.

IV. Workmanship and Finish.

12. The finished castings shall conform substantially to the sizes and shapes of the patterns, shall be made in a workmanlike manner, and be free from injurious defects.

13. Minor defects which do not impair the strength of the castings may, with the approval of the purchaser, be welded by an approved process. The defects shall first be cleaned out to solid metal, and, after welding, the castings shall be annealed.

14. Castings offered for inspection shall not be painted or covered with any substance that will hide defects, nor rusted to such an extent as to hide defects.

ALLOY STEELS

In connection with the purchase and use of alloy steels it should be borne in mind that such steels should be used in the treated condition only, that is, not in an annealed or natural condition. In the latter condition there is a slight benefit, perhaps, as compared with plain carbon steels, but as a rule nothing commensurate with the increased cost. In the heat-treated condition, however, there is a very marked improvement in physical characteristics.

NICKEL STEELS

SPECIFICATION NO. 2315

.15 Carbon, 3½% Nickel Steel

This quality of steel is embraced in these specifications to furnish a nickel steel that is suitable for carbonizing purposes. Steel of this character, properly carbonized and heat-treated, will produce a part with an exceedingly tough and strong core, coupled with the desired high carbon exterior.

This steel is also available for structural purposes, but is not one to be selected for such purpose when ordering materials. Much better results will be obtained with one of the other nickel steels of higher carbon.

It is intended for case-hardened gears, for both the bevel driving and transmission systems, and for such other case-hardened parts as demand a very tough, strong steel with a hardened exterior.

The case-hardening sequence may be varied considerably, as with Steel 1020, those parts of relatively small importance requiring a simpler form of treatment. As a rule, however, those parts which require the use of nickel steel require the best type of case-hardening, viz.:

Heat Treatment G

After forging or machining:

1. Carbonize at a temperature between 1600° Fahr. and 1750° Fahr. (1650°-1700° Fahr. desired).
2. Cool slowly in the carbonizing material.
3. Reheat to 1500°-1550° Fahr.
4. Quench.
5. Reheat to 1300°-1400° Fahr.
6. Quench.
7. Reheat to 250°-500° Fahr. (in accordance with the necessities of the case) and cool slowly.

The second quench (Operation 6) must be conducted at the lowest possible temperature at which the material will harden. It will be found that sometimes this is lower than 1300° Fahr.

In connection with certain uses it will be found possible to omit the final drawing (Operation 7) entirely, but for parts of the highest importance this operation should be followed as a safeguard. Parts of intricate shape, with sudden changes of thickness, sharp corners and the like, particularly sliding gears, should always be drawn, in order to relieve the internal strain.

Much is to be learned from the character of the fracture. The center should be fibrous in appearance, and the exterior, high-carbon metal closely crystalline, or even silky.

When used for structural purposes, the physical characteristics will range about as follows:

Physical Characteristics

	Annealed	Heat Treatment H or K
Yield point, lbs. per sq. in.........	35,000 to 45,000	40,000 to 80,000
Reduction of area	65-45%	65-40%
Elongation in 2″	35-25%	35-15%

SPECIFICATION NO. 2320

.20 Carbon, 3½% Nickel Steel

This quality may be used interchangeably with Steel 2315. Although intended primarily for case-hardening, it may be properly

used for structural parts, with suitable heat treatment, and will
give elastic limits somewhat higher than material provided by
the preceding specification.

For case-hardening, Heat Treatment G should be followed, and
for structural purposes the treatment should be in accordance
with Heat Treatment H or K, the quenching temperatures, as
with other steels, being modified to meet individual cases.

Heat Treatment K

After forging or machining:
1. Heat to 1500°-1550° Fahr.
2. Quench.
3. Reheat to 1300°-1400° Fahr.
4. Quench.
5. Reheat to 600°-1200° Fahr. and cool slowly.

Physical Characteristics

	Annealed	Heat Treatment H or K
Yield point, lbs. per sq. in	40,000 to 50,000	50,000 to 125,000
Reduction of area	65-40%	65-40%
Elongation in 2″	30-20%	25-10%

SPECIFICATION NO. 2330

.30 Carbon, 3½% Nickel Steel

This quality of steel is primarily for heat-treated structural
parts where strength and toughness are sought, such parts as
axles, front-wheel spindles, crankshafts, driving-shafts and trans-
mission shafts. Wide variations of yield point or elastic limit
are possible by the use of different quenching mediums—oil, water
or brine—and variation in drawing temperatures, from 500° Fahr.
up to 1200° Fahr. (Heat Treatment H).

A higher refinement of this treatment is Heat Treatment K.

Physical Characteristics

The physical characteristics of this steel may be considered as
practically those obtained with Steel 2320, slight modifications

in the treatment much more than offsetting the slight difference in the carbon content.

	Annealed	Heat Treatment H or K
Yield point or elastic limit, lbs. per sq. in.	40,000 to 50,000	60,000 to 130,000
Reduction of area	60-40%	60-30%
Elongation in 2″	30-20%	25-10%

SPECIFICATION NO. 2335

.35 Carbon, 3½% Nickel Steel

This quality of steel is subject to precisely the same remarks as Steel 2330. It will respond a little more sharply to heat treatment, and can be forced to higher elastic limits. The difference will be small except in extreme cases.

Physical Characteristics

	Annealed	Heat Treatment H or K
Yield point or elastic limit, lbs. per sq. in.	45,000 to 55,000	65,000 to 160,000
Reduction of area	55-35%	55-25%
Elongation in 2″	25-15%	25-10%

SPECIFICATION NO. 2340

.40 Carbon, 3½% Nickel Steel

The above nickel steel is a quality not in wide use but available for certain purposes. The carbon content being higher than generally used, greater hardness is obtainable by quenching; and, as increased brittleness accompanies the greater hardness, the treatments given must be modified to meet such condition. For example, the final quench may be at a considerably lower temperature, and the final drawing temperature, or partial annealing, must be carefully chosen, in order to produce the desired toughness and other physical characteristics.

Physical Characteristics

	Annealed	Heat Treatment H or K
Yield point or elastic limit, lbs. per sq. in.	55,000 to 65,000	70,000 to 200,000
Reduction of area	50-30%	55-15%
Elongation in 2″	25-15%	20- 5%

NICKEL CHROMIUM STEELS

In general it may be said in the case of the Nickel Chromium Steels that the heat treatments and the properties induced thereby are much the same as in the case of plain nickel steels, except that the effects of the heat treatments are somewhat augmented by the presence of the chromium, and, further, that these effects increase with increasing amounts of nickel and chromium.

SPECIFICATION NO. 3120

This quality of steel is intended primarily for case-hardening (Heat Treatment G). It may also be used for structural parts with suitable heat treatment (Heat Treatment H or D). It should not be used in the natural or untreated condition.

Physical Characteristics

	Annealed	Heat Treatment H or D
Yield point or elastic limit, lbs. per sq. in.	30,000 to 40,000	40,000 to 100,000
Reduction of area	55-40%	65-40%
Elongation in 2″	35-25%	25-15%

SPECIFICATIONS NOS. 3125, 3130, 3135, 3140

These qualities of steel are intended primarily for structural purposes in a heat-treated condition (Heat Treatment H, D or E). Steel 3125 may be used for case-hardening, as also may Steel 3130 if necessary.

PHYSICAL CHARACTERISTICS

STEELS 3125, 3130:

	Annealed	Heat Treatment H, D or E
Yield point or elastic limit, lbs. per sq. in.	40,000 to 55,000	50,000 to 125,000
Reduction of area	50-35%	55-25%
Elongation in 2″	30-20%	25-10%

STEELS 3135, 3140:

	Annealed	Heat Treatment H, D or E
Yield point or elastic limit, lbs. per sq. in.	45,000 to 60,000	55,000 to 150,000
Reduction of area	45-30%	50-25%
Elongation in 2″	25-15%	20 -5%

SPECIFICATION NO. 3220

This steel is intended for case-hardened parts of nickel chromium steel. Case-hardened parts demanding this grade of steel also demand the most careful heat treatment (Heat Treatment G). It may also be used for structural purposes with Heat Treatment H or D.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment H or D
Yield point or elastic limit, lbs. per sq. in.	35,000 to 45,000	45,000 to 120,000
Reduction of area	60-45%	65-30%
Elongation in 2″	25-20%	20- 5%

SPECIFICATION NO. 3230

This steel is intended for the most important structural parts, and should be used only in a heat-treated condition (Heat Treatment H or D).

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment H or D
Yield point or elastic limit, lbs. per sq. in.	40,000 to 50,000	60,000 to 175,000
Reduction of area	55-40%	60-30%
Elongation in 2″	25-15%	20- 5%

SPECIFICATION NO. 3240

This quality of steel is suitable for structural parts where unusual strength is demanded. Higher elastic limit is possible under a given treatment than with material like Steel 3230. The toughness will not be quite as great, but this does not bar the material from uses where toughness is not the controlling factor and where strength is.

Heat Treatment H or D is recommended.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment H or D
Yield point or elastic limit, lbs. per sq. in.	45,000 to 60,000	65,000 to 200,000
Reduction of area	50-40%	50-20%
Elongation in 2″	25-15%	15- 2%

SPECIFICATION NO. 3250

This steel is intended for gears where extreme strength and hardness are necessary.

To heat-treat for gears, either Heat Treatment M or Q should be followed, the latter giving the better results.

HEAT TREATMENT M

After forging or machining:
1. Heat to 1450°-1500° Fahr.
2. Quench.
3. Reheat to 500°-1250° Fahr. and cool slowly.

A higher refinement of this same treatment is:

HEAT TREATMENT Q

After forging:
1. Heat to 1475°-1525° Fahr. (Hold at this temperature one-half hour to insure thorough heating.)
2. Cool slowly.
3. Reheat to 1375°-1425° Fahr.
4. Quench.
5. Reheat to 250°-550° Fahr. and cool slowly.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment M or Q
Yield point or elastic limit, lbs. per sq. in.	50,000 to 60,000	150,000 to 250,000
Reduction of area	50-40%	25-15%
Elongation in 2″	25-15%	15- 2%

SPECIFICATION X3315

This steel is intended primarily for case-hardening. It is higher in nickel and chromium than the preceding nickel chromium steels. Heat Treatment G should be followed.

It is sometimes used for structural parts, when Heat Treatment M is applicable.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment M
Yield point or elastic limit, lbs. per sq. in.	35,000 to 45,000	40,000 to 100,000
Reduction of area	60-45%	65-30%
Elongation in 2″	25-20%	20- 5%

SPECIFICATION X3335

This steel is intended for structural parts of the most important character, such as crankshafts, axles, spindles, drive-shafts and transmission shaft. Heat Treatment P or R is recommended.

This steel is not intended for case-hardening.

HEAT TREATMENT P

After forging or machining:

1. Heat to 1450°-1500° Fahr.
2. Quench.
3. Reheat to 1375°-1450° Fahr.
4. Quench.
5. Reheat to 500°-1250° Fahr. and cool slowly.

HEAT TREATMENT R

After forging:

1. Heat to 1500°-1550° Fahr.
2. Quench in oil.
3. Reheat to 1200°-1300°.   (Hold at this temperature three hours.)
4. Cool slowly.
5. Machine.
6. Reheat to 1350°-1450° Fahr.
7. Quench in oil.
8. Reheat to 250°-500° Fahr. and cool slowly.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment P or R
Yield point or elastic limit, lbs. per sq. in.	45,000 to 55,000	60,000 to 175,000
Reduction of area	55-40%	60-30%
Elongation in 2″	25-15%	20- 5%

SPECIFICATION X3350

This steel is an alternative quality for gears. The remarks made on Steel 3250 apply to this case. The physical characteristics are similar to those of Steel 3250. Heat Treatment R should be used, although P is applicable.

SPECIFICATION NO. 3320

The remarks made in connection with Steel 3220 apply to this steel also. There is no appreciable difference in the physical characteristics. Carbonizing should follow the practice indicated under Heat Treatment L.

HEAT TREATMENT L

After forging or machining:

1. Carbonize at a temperature between 1600° Fahr. and 1750° Fahr. (1650°-1700° Fahr. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1400°-1500° Fahr.
4. Quench.
5. Reheat to 1300°-1400° Fahr.
6. Quench.
7. Reheat to 250°-500° Fahr. and cool slowly.

SPECIFICATION NO. 3330

This steel, like No. 3230, is intended for very important structural parts. The high nickel and chromium contents make it exceedingly tough and strong when treated according to Heat Treatment P or R.

SPECIFICATION NO. 3340

This steel is suitable for gears to be hardened without carbonizing. The remarks made in connection with Steels 3240 and 3250 apply. Heat Treatment P or R should be used.

CHROMIUM STEELS

SPECIFICATION NO. 5120

This steel is similar in properties to 2320 and 3120 in that it is a case-hardening grade of much better quality than carbon steel. Heat Treatment B should be used.

SPECIFICATION NO. 5140

This grade of steel is very similar in properties to Steel 3140. When treated according to H or D it becomes useful for high-

duty shafting, etc. The drawing temperature should be moderately high in order to maintain a safe degree of toughness.

SPECIFICATIONS NOS. 5195, 51120, 5295, 52120

These four grades of steel are used almost exclusively for ball bearing cups and cones where their extreme hardness is indispensable. The treatment of these steels is in the hands of specialists, but in a general way Treatment P and R illustrate the procedures followed.

CHROMIUM VANADIUM STEELS

SPECIFICATION NO. 6120

.20 Carbon, Chromium Vanadium Steel

This quality is also primarily for case-hardening. It is used for the most important case-hardened parts; that is, case-hardened shafts, gears and the like.

This steel may also be used in a heat-treated condition for structural purposes, but for such work some of the specifications following are to be preferred, particularly where higher strength is desired.

The case-hardening treatment recommended is that covered by Heat Treatment S.

Heat Treatment S

After forging or machining:
1. Carbonize at a temperature between 1600° Fahr. and 1750° Fahr. (1650°-1700° Fahr. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1650°-1750° Fahr.
4. Quench.
5. Reheat to 1475°-1550° Fahr.
6. Quench.
7. Reheat to 250°-550° Fahr. and cool slowly.

For structural purposes the following heat treatment is recommended:

Heat Treatment T

After forging or machining:
1. Heat to 1650°-1750° Fahr.

2. Quench.
3. Reheat to 500°-1300° Fahr. and cool slowly.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment T
Yield point or elastic limit, lbs. per sq. in.	40,000 to 50,000	55,000 to 100,000
Reduction of area................	65-50%	65-45%
Elongation in 2″	30-20%	25-10%

SPECIFICATION NO. 6125

.25 CARBON, CHROMIUM VANADIUM STEEL

The difference between this and the preceding specification is very slight, and they may be used interchangeably for structural purposes. This steel may be case-hardened, but is not first choice for this purpose.

The physical characteristics may be considered as practically the same as given for Steel 6120.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment T
Yield point or elastic limit, lbs. per sq. in.	40,000 to 50,000	55,000 to 100,000
Reduction of area	65-50%	65-45%
Elongation in 2″	32-20%	25-10%

SPECIFICATION NO. 6130

.30 CARBON, CHROMIUM VANADIUM STEEL

This quality of steel is intermediate in the carbon range, and may be used interchangeably with Steel 6125 for structural purposes. It should not be used for case-hardening. When subjected to Heat Treatment T it possesses a high degree of combined strength and toughness.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment T
Yield point or elastic limit, lbs. per sq. in.	45,000 to 55,000	60,000 to 150,000
Reduction of area	60-50%	55-25%
Elongation in 2″	25-20%	15- 5%

SPECIFICATION NO. 6135

.35 CARBON, CHROMIUM VANADIUM STEEL

This specification provides a first-rate quality of steel for structural parts that are to be heat-treated. The fatigue-resisting (endurance) qualities of this material are excellent.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment T
Yield point or elastic limit, lbs. per sq. in.	45,000 to 55,000	60,000 to 150,000
Reduction of area	60-50%	55-25%
Elongation in 2″	25-20%	15- 5%

SPECIFICATION NO. 6140

.40 CARBON, CHROMIUM VANADIUM STEEL

This is a very good quality of steel to be selected where a high degree of strength is desired, coupled with a good measure of toughness. Its fatigue-resisting qualities are very high, and it is a first-class material for high-duty shafts.

Heat Treatment T is recommended.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment T
Yield point or elastic limit, lbs. per sq. in.	50,000 to 60,000	65,000 to 175,000
Reduction of area	55-45%	50-15%
Elongation in 2″	25-15%	15- 2%

11

SPECIFICATION NO. 6145

.45 Carbon, Chromium Vanadium Steel

This quality of steel contains sufficient carbon in combination with chromium and vanadium to harden to a considerable degree when quenched at a proper temperature, and may be used for gears and springs.

For structural parts where exceedingly high strength is desirable, Heat Treatment T should be followed.

For gears this steel should be annealed after forging, and before machining, the anneal to consist of Operations 1 and 2 of the following:

Heat Treatment U

After forging:
1. Heat to 1525°-1600° Fahr.   (Hold at this temperature one-half hour to insure thorough heating.)
2. Cool slowly.
3. Reheat to 1650°-1700° Fahr.
4. Quench.
5. Reheat to 350°-550° and cool slowly   .

This last drawing operation may be modified to obtain any desired hardness.

Physical Characteristics

	Annealed	Heat Treatment U
Yield point or elastic limit, lbs. per sq. in.	55,000 to 65,000	150,000 to 200,000
Reduction of area	55-40%	25-10%
Elongation in 2″	25-15%	10- 2%

SPECIFICATION NO. 6150

.50 Carbon, Chromium Vanadium Steel

Substantially the same remarks as made in regard to Steel 6145 apply to this quality. In this grade, however, we also find a material that is suitable for springs. With a proper sequence of heating, quenching and drawing, very high elastic limits are obtained.

For spring material Heat Treatment U is recommended, except

that the last drawing (Operation 5) will be carried farther—probably from 700°-1100° Fahr. This final drawing temperature will have to vary with the section of material being handled, whether light spiral springs or heavy flat springs.

PHYSICAL CHARACTERISTICS

	Annealed	Heat Treatment U
Yield point or elastic limit, lbs. per sq. in.	60,000 to 70,000	150,000 to 225,000
Reduction of area	50-35%	35-15%
Elongation in 2″	20-15%	10- 2%

SILICO-MANGANESE STEELS

SPECIFICATIONS NOS. 9250 AND 9260

These steels have been standardized by using principally as spring steels. No. 9260 is also used to some extent for gears. Neither steel is suitable for use without heat treatment.

Both of these specifications are provided in order to meet the requirements of two groups of users: those who believe in relatively low carbon and high silicon, and those who desire higher carbon and lower silicon. When properly treated their physical properties will not differ appreciably, though Steel 9250 will probably be slightly the tougher of the two. Heat Treatment V is suitable for both gears and springs.

HEAT TREATMENT V

After forging or machining:
 1. Heat to 1650°-1750° Fahr.
 2. Quench.
 3. Reheat to 400°-1200° Fahr. and cool slowly.

Steel 9260 will become harder when quenched in the same medium as Steel 9250. The latter, however, is more often quenched in water, while Steel 9260 is generally quenched in oil—a circumstance which largely counteracts the influence of the composition. Furthermore, variation in the temperature of drawing will suffice to balance the properties closely.

The exact temperature for quenching and drawing and the proper medium should be determined for each case. In general, gears are drawn between 450° and 550° Fahr., and springs between 800° and 1000° Fahr.

Physical Characteristics

	Annealed	Heat Treatment V
Yield point or elastic limit, lbs. per sq. in.	55,000 to 65,000	60,000 to 180,000
Reduction of area	45-30%	40-10%
Elongation in 2″	25-20%	20- 5%

PHYSICAL PROPERTIES OF HEAT TREATED CARBON STEELS

In interpreting the physical property curves and tabulations given in the following data, these considerations should be borne in mind:

1. The figures given have been made as valuable as possible to the engineer by indicating what can be expected as the average product of a given composition when treated in the specified manner, in average sections prevailing in motor car work.

2. At the same time the data have been so chosen as to protect makers of treated stock and parts from unreasonable demands. This has been done by taking figures low enough to be obtained with reasonable certainty when open market stock of medium to high grade is treated in commercially efficient equipment, controlled by commercially accurate instruments.

For the sake of simplicity only average minimum figures for tensile strength, elastic limit, reduction of area and elongation have been adopted; these figures are based upon the following assumptions, heat treatment being kept constant:

1. The lowest tensile strength and elastic limit are produced with steels at the bottom of a given range in carbon.

2. The lowest reduction in area and elongation are produced with steels at the top of a given range in carbon.

Thus, for 1035 steel, the tensile strengths and elastic limits given are the average minimum as of a steel containing .30 per cent. carbon; the reductions of area and elongation are the average minimum as of a steel containing .40 per cent. carbon.

True elastic limits are given because they are consistently lower than the corresponding yield points.

The figures for hardness are conventional averages for the whole range of compositions within any given specification. In general, the Brinell hardness figure is subject to fluctuations of plus or minus ten to fifteen points, the Shore (scleroscope) hardness of plus or minus five points.

Specimens for test must comply with all the requirements given under remarks concerning general physical property data. In addition, tensile test pieces are to be taken concentrically from bars which are treated in diameters up to and including one inch round or square; from larger sections the axis of the test piece should be made parallel to the axis of the bar at any point as nearly as possible 50 per cent. from the center to the exterior.

PHYSICAL CHARACTERISTICS OF HEAT TREATED· S. A. E. STEEL NO. 1020
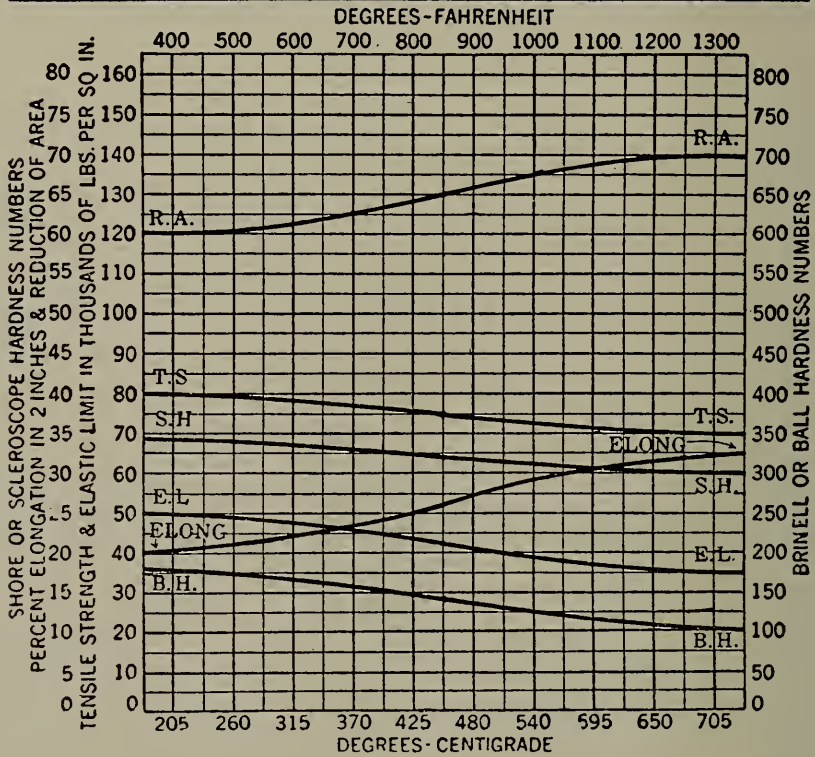
Heat Treatment

The accompanying data apply to ½ in. to 1½ in. round specimens which were heated from 15 to 30 min at 1560° to 1580° Fahr.; quenched in oil; reheated for 30 min. at temperatures indicated by the abscissae of the curves; and finally cooled in air. (Heat Treatment H.)

TABULATION OF VALUES PLOTTED IN CURVE

Reheating Temperature, Deg. F.	Tensile Strength, Lb. per Sq. In.	Elastic Limit, Lb. per Sq. In.	Reduction of Area, per Cent.	Elongation in 2 In., per Cent.	Brinell Hardness	Scleroscope Hardness
400	80,000	50,000	60.0	20.0	180	34
500	79,000	49,000	60.5	20.5	175	34
600	78,000	48,000	61.0	21.0	170	34
700	77,000	46,500	62.0	22.5	160	33
800	76,000	44,500	63.5	24.5	150	33
900	75,000	42,500	65.0	26.5	140	32
1000	74,000	40,500	66.5	28.5	130	32
1100	73,000	38,500	68.0	30.0	120	31
1200	72,000	37,000	69.0	31.5	110	31
1300	71,000	36,000	69.5	32.0	105	30
1400	70,000	35,000	70.0	32.5	100	30

Values are average minimum, except those for hardness, which are average.

PHYSICAL CHARACTERISTICS OF HEAT TREATED· S. A. E. STEEL NO. 1025
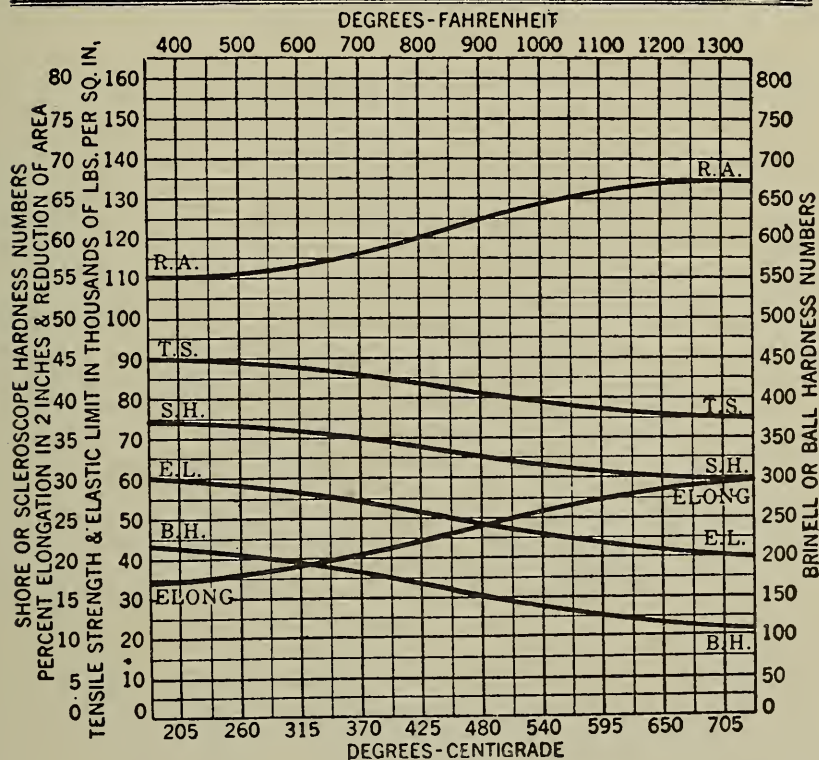
Heat Treatment

The accompanying data apply to ½ in. to 1½ in. round specimens which were heated from 15 to 30 min. at 1540° to 1560° Fahr.; quenched in oil; reheated for 30 min. at temperatures indicated by the abscissae of the curves; and finally cooled in air. (Heat Treatment H.)

TABULATION OF VALUES PLOTTED IN CURVE

Reheating Tempera-ture, Deg. F.	Tensile Strength, Lb. per Sq. In.	Elastic Limit, Lb. per Sq. In.	Reduc-tion of Area, per Cent.	Elonga-tion in 2 In., per Cent.	Brinell Hard-ness	Sclero-scope Hard-ness
400	90,000	60,000	55.0	17.0	215	37
500	89,000	59,000	55.5	17.5	210	37
600	88,000	57,000	56.0	18.5	200	36
700	86,500	55,000	57.5	20.0	185	36
800	84,500	52,500	59.0	21.5	175	35
900	82,500	50,000	61.0	23.5	160	34
1000	80,500	47,500	63.0	25.5	145	33
1100	78,500	45,000	64.5	27.0	135	32
1200	77,000	43,000	66.0	28.5	125	31
1300	76,000	41,000	67.0	29.5	115	30
1400	75,000	40,000	67.5	30.0	110	30

Values are average minimum, except those for hardness, which are average.

PHYSICAL CHARACTERISTICS OF HEAT TREATED· S. A. E. STEEL NO. 1035
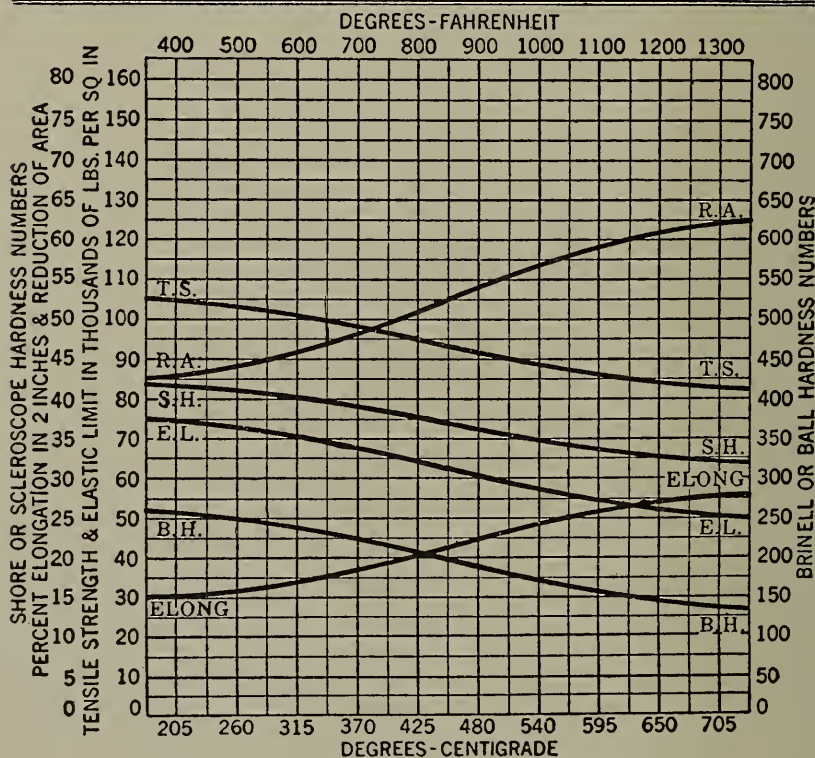
Heat Treatment

The accompanying data apply to ½ in. to 1½ in. round specimens which were heated from 15 to 30 min. at 1510° to 1530° Fahr.; quenched in oil; reheated for 30 min. at temperatures indicated by the abscissae of the curves; and finally cooled in air. (Heat Treatment H.)

TABULATION OF VALUES PLOTTED IN CURVE

Reheating Temperature, Deg. F.	Tensile Strength, Lb. per Sq. In.	Elastic Limit, Lb. per Sq. In.	Reduction of Area, per Cent.	Elongation in 2 In., per Cent.	Brinell Hardness	Scleroscope Hardness
400	105,000	75,000	42.5	15.0	260	42
500	104,000	74,000	43.5	15.5	255	42
600	102,500	72,000	45.0	16.5	245	41
700	100,000	69,000	47.0	18.0	235	40
800	97,000	66,000	49.5	19.5	220	39
900	94,000	63,000	52.5	21.5	200	37
1000	91,000	59,500	55.5	23.5	180	35
1100	88,000	56,000	58.0	25.0	165	34
1200	85,500	53,000	60,0	26.5	150	33
1300	83,500	51,000	61.5	27.5	140	32
1400	82,000	50,000	62.5	28.0	135	32

Values are average minimum, except those for hardness, which are average.

PHYSICAL CHARACTERISTICS OF HEAT TREATED·S. A. E. STEEL NO. 1045
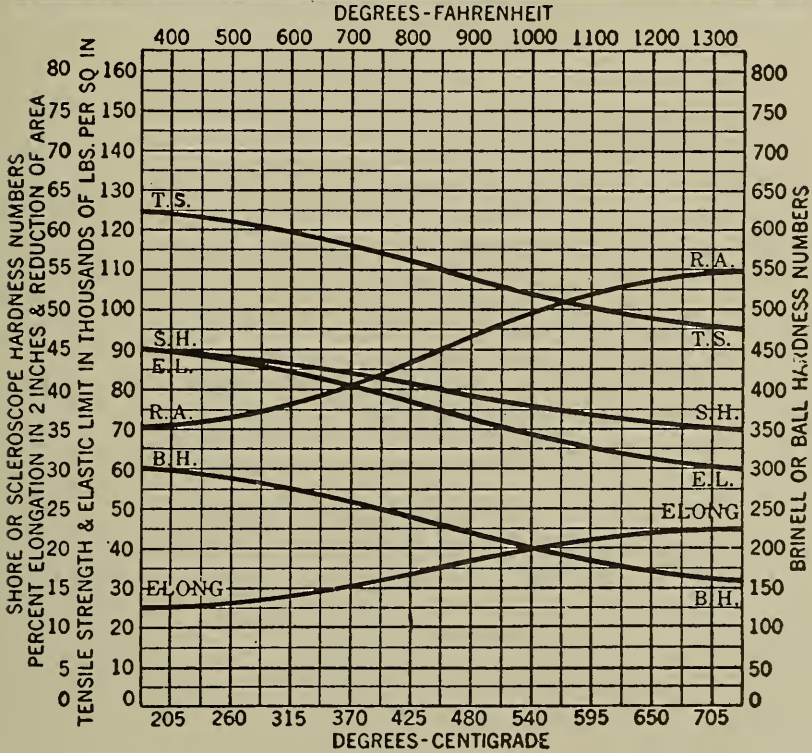
Heat Treatment

The accompanying data apply to ½ in. to 1½ in. round specimens which were heated from 15 to 30 min. at 1490° to 1510° Fahr.; quenched in oil; reheated for 30 min. at temperatures indicated by the abscissae of the curves; and finally cooled in air. (Heat Treatment H.)

TABULATION OF VALUES PLOTTED IN CURVE

Reheating Temperature, Deg. F.	Tensile Strength, Lb. per Sq. In.	Elastic Limit, Lb. per Sq. In.	Reduction of Area, per Cent.	Elongation in 2 In., per Cent.	Brinell Hardness	Scleroscope Hardness
400	125,000	90,000	35.0	12.5	300	45
500	123,500	88,000	36.0	13.0	290	45
600	121,000	85,500	37.0	13.5	280	44
700	118,000	82,500	39.0	14.5	265	43
800	114,000	79,000	42.0	16.0	250	41
900	110,000	75,000	45.0	17.5	230	40
1000	106,000	71,000	48.0	19.0	210	38
1100	102,000	67,000	50.5	20.5	195	37
1200	99,000	63,500	53.0	21.5	180	36
1300	96,500	61,500	54.0	22.0	165	35
1400	95,000	60,000	55.0	22.5	160	35

Values are average minimum, except those for hardness, which are average.

INDEX

INDEX

HEAT TREATMENTS

Heat Treatment A

After forging or machining:
Carbonize between 1600° F. and 1750° F. (1650°-1750° F. desired.)
Cool slowly or quench.
Reheat to 1450°-1500° F. and quench.

Heat Treatment B

After forging or machining:
Carbonize between 1600° F. and 1750° F. (1650°-1700° F. desired.)
Cool slowly in the carbonizing mixture.
Reheat to 1550°-1625° F. Quench.
Reheat to 1400°-1450° F. Quench.
Draw in hot oil at 300° to 450° F., depending upon the degree of hardness desired.

Heat Treatment D

After forging or machining:
Heat to 1500°-1600° F.
Quench.
Reheat to 1450°-1500° F. Quench.
Reheat to 600°-1200° F. and cool slowly.

Heat Treatment E

After forging or machining:
Heat to 1500°-1550° F.
Cool slowly.
Reheat to 1450°-1550° F. Quench.
Reheat to 600°-1200° F. and cool slowly.

Heat Treatment F

After shaping or coiling:
Heat to 1425°-1475° F.
Quench in oil.
Reheat to 400°-900° F., in accordance with temper desired, and cool slowly.

Heat Treatment G

After forging or machining:
1. Carbonize between 1600° F. and 1750° F. (1650°-1700° F. desired.)
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1500°-1550° F.
4. Quench.

5. Reheat to 1300°-1400° F.
6. Quench.
7. Reheat to 250°-500° F. (in accordance with the necessities of the case) and cool slowly.

Heat Treatment H

After forging or machining:
1. Heat to 1500°-1600° F.
2. Quench.
3. Reheat to 600°-1200° F. and cool slowly.

Heat Treatment K

After forging or machining:
1. Heat to 1500°-1550° F.
2. Quench.
3. Reheat to 1300°-1400° F.
4. Quench.
5. Reheat to 600°-1200° F. and cool slowly.

Heat Treatment L

After forging or machining:
1. Carbonize between 1600° F. and 1750° F. (1650°-1700° F. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1400°-1500° F.
4. Quench.
5. Reheat to 1300°-1400° F.
6. Quench.
7. Reheat to 250°-500° F. and cool slowly.

Heat Treatment M

After forging or machining:
1. Heat to 1450°-1500° F.
2. Quench.
3. Reheat to 500°-1250° F. and cool slowly.

Heat Treatment P

After forging or machining:
1. Heat to 1450°-1500° F.
2. Quench.
3. Reheat to 1375°-1450° F.
4. Quench.
5. Reheat to 500°-1250° F. and cool slowly.

Heat Treatment Q

After forging:
1. Heat to 1475°-1525° F. (Hold at this temperature one-half hour, to insure thorough heating).

2. Cool slowly.
3. Machine.
4. Reheat to 1375°-1425° F.
5. Quench.
6. Reheat to 250°-550° F. and cool slowly.

Heat Treatment R

After forging:
1. Heat to 1500°-1550° F.
2. Quench in oil.
3. Reheat to 1200°-1300° F. (Hold at this temperature three hours.)
4. Cool slowly.
5. Machine.
6. Reheat to 1350°-1450° F.
7. Quench in oil.
8. Reheat to 250°-500° F. and cool slowly.

Heat Treatment S

After forging or machining:
1. Carbonize at a temperature between 1600° F. and 1750° F. (1650°-1700° F. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1650°-1750° F.
4. Quench.
5. Reheat to 1475°-1550° F.
6. Quench.
7. Reheat to 250°-550° F. and cool slowly.

Heat Treatment T

After forging or machining:
1. Heat to 1650°-1750° F.
2. Quench.
3. Reheat to 500°-1300° F. and cool slowly.

Heat Treatment U

After forging:
1. Heat to 1525°-1600° F. (Hold for about one-half hour.)
2. Cool slowly.
3. Machine.
4. Reheat to 1650°-1700° F.
5. Quench.
6. Reheat to 350°-550° F. and cool slowly.

Heat Treatment V

After forging or machining:
1. Heat to 1650°-1750° F.
2. Quench.
3. Reheat to 400°-1200° F. and cool slowly.

Silico5 per cent. to .50 per cent.

CHART OF STEEL SPECIFICATIONS—AMERICAN SOCIETY OF AUTOMOTIVE ENGINEERS—WITH RECOMMENDED HEAT TREATMENTS

Class	S.A.E. Spec. No.	Carbon Min. and Max.	Carbon Desired	Manganese Min. and Max.	Manganese Desired	Phosphorus (Max.)	Sulphur (Max.)	Nickel Min. and Max.	Nickel Desired	Chromium Min. and Max.	Chromium Desired	Vanadium Min. and Max.	Vanadium Desired	Silicon Min. and Max.	Silicon Desired	Heat Treatment
Carbon Steels	1010	0.05 to 0.15	0.10	0.30 to 0.60	0.45	0.045	0.05	‡	‡	‡	‡	‡	‡	‡	‡	Quench 1500° F.
" "	1020	.15 to .25	.20	.30 to .60	.45	.045	.05	‡	‡	‡	‡	‡	‡	‡	‡	H, A or B
" "	1025	.20 to .30	.25	.50 to .80	.65	.045	.05	‡	‡	‡	‡	‡	‡	‡	‡	H or D
" "	1035	.30 to .40	.35	.50 to .80	.65	.045	.05	‡	‡	‡	‡	‡	‡	‡	‡	H, D or E
" "	1045	.40 to .50	.45	.50 to .80	.65	.045	.05	‡	‡	‡	‡	‡	‡	‡	‡	H, D or E
" "	1095	.90 to 1.05	.05	.25 to .50	35	.04	.05	‡	‡	‡	‡	‡	‡	‡	‡	F
Screw Stock	1114	0.08 to 0.20	‡	0.30 to 0.80	‡	0.12	0 06 to 0.12	‡	‡	‡	‡	‡	‡	‡	‡	
Steel Castings	1235	As required for physical properties	‡	‡	‡	0.05	0.05	‡	‡	‡	‡	‡	‡	‡	‡	
Nickel Steels	2315	0.10 to 0.20	0.15	0.50 to 0.80	0.65	0.04	0.045	3.25 to 3.75	3.50	‡	‡	‡	‡	‡	‡	G, H or K
" "	2320	.15 to .25	.20	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50	‡	‡	‡	‡	‡	‡	G, H or K
" "	2330	.25 to .35	.30	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50	‡	‡	‡	‡	‡	‡	H or K
" "	2335	.30 to .40	.35	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50	‡	‡	‡	‡	‡	‡	H or K
" "	2340	.35 to .45	.40	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50	‡	‡	‡	‡	‡	‡	H or K
" "	2345	.40 to .50	.45	.50 to .80	.65	.05	.045	3.25 to 3.75	3.50	‡	‡	‡	‡	‡	‡	H or K
Nickel Chromium Steels	3120	0.15 to 0.25	0.20	0.50 to 0.80	0.05	0.04	0.045	1.00 to 1.50	1.25	0.45 to 0.75*	0.00	‡	‡	‡	‡	G, H or D
" " "	3125	.20 to .30	.25	.50 to .80	.55	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.60	‡	‡	‡	‡	H, D or E
" " "	3130	.25 to .35	.30	.50 to .80	.65	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.60	‡	‡	‡	‡	H, D or E
" " "	3135	.30 to .40	.35	.50 to .80	.65	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.00	‡	‡	‡	‡	H, D or E
" " "	3140	.35 to .45	.40	.50 to .80	.65	.01	.045	1.00 to 1.50	1.25	.45 to .75*	.00	‡	‡	‡	‡	H, D or E
" " "	3220	.15 to .25	.20	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10	‡	‡	‡	‡	G, H or D
" " "	3230	.25 to .35	.30	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10	‡	‡	‡	‡	H or D
" " "	3240	.35 to .45	.40	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10	‡	‡	‡	‡	H or D
" " "	3250	.45 to .55	.50	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10	‡	‡	‡	‡	M or Q
" " "	X3315	.10 to .20	.15	.45 to .75	.60	.04	.04	2.75 to 3.25	3.00	.00 to .95	.80	‡	‡	‡	‡	G or M ||
" " "	X3335	.30 to .40	.35	.45 to .75	.60	.04	.04	2.75 to 3.25	3.00	.60 to .95	.80	‡	‡	‡	‡	P or R
" " "	X3350	.45 to .55	.50	.45 to .75	.60	.04	.04	2.75 to 3.25	3.00	.60 to .95	.80	‡	‡	‡	‡	P or R
" " "	3320	.15 to .25	.20	.30 to .00	.45	.04	.04	3.25 to 3.75	3.50	1.25 to 1.75	1.50	‡	‡	‡	‡	L
" " "	3330	.25 to .35	.30	.30 to .60	.45	.04	.04	3.25 to 3.75	3.50	1.25 to 1.75	1.50	‡	‡	‡	‡	P or R
" " "	3340	.35 to .45	.40	.30 to .60	.45	.04	.04	3.25 to 3.75	3.50	1.25 to 1.75	1.50	‡	‡	‡	‡	P or R
Chromium Steels	5120	0.15 to 0.25	0.20	†	†	0.04	0.045	‡	‡	0.65 to 0.85	0.75	‡	‡	‡	‡	B
" "	5140	.35 to .45	.40	†	†	.04	.045	‡	‡	.65 to .85	.75	‡	‡	‡	‡	H or D
" "	5165	.60 to .70	.65	†	†	.04	.045	‡	‡	.65 to .65	.75	‡	‡	‡	‡	H or D
" "	5195	.90 to 1.05	.95	0.20 to 0.45	0.35	.03	.03	‡	‡	.90 to 1.10	1.00	‡	‡	‡	‡	M, P or R
" "	51120	1.10 to 1.30	1.20	.20 to .45	.35	.03	.03	‡	‡	.90 to 1.10	1.00	‡	‡	‡	‡	M, P or R
" "	5295	.90 to 1.05	.95	20 to .45	.35	.03	.03	‡	‡	1.10 to 1.30	1.20	‡	‡	‡	‡	M, P or R
" "	52120	1.10 to 1.30	1.20	.20 to .45	.35	.03	.03	‡	‡	1.10 to 1.30	1.20	‡	‡	‡	‡	M, P or R
Chromium Vanadium Steels	6120	0.15 to 0.25	0.20	0.50 to 0.80	0.65	0.04	0.04	‡	‡	0.80 to 1.10	0.95	0.15	0.18	‡	‡	S or T ¶
" " "	6125	.20 to .30	.25	.50 to .80	.65	.04	.04	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	S or T
" " "	6130	.25 to .35	.30	.50 to .80	.65	.04	.04	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	T or U
" " "	6135	.30 to .40	.35	.50 to .80	.65	.05	.04	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	T or U
" " "	6140	.35 to .45	.40	.50 to .80	.65	.04	.04	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	T or U
" " "	6145	40 to .50	.45	.50 to .80	.65	.04	.04	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	U
" " "	6150	.45 to .55	.50	.50 to .80	.65	.04	.04	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	U
" " "	6195	.00 to 1.05	.95	.20 to .45	.35	.03	.03	‡	‡	.80 to 1.10	.95	.15	.18	‡	‡	U
Silico-Manganese Steels	9250	0.45 to 0.55	0.50	0.00 to 0.80	0.70	0.045§	0.045	‡	‡	‡	‡	‡	‡	1.80 to 2.10	1.95	V
" "	0260	.55 to .65	.60			.045§	.045	‡	‡	‡	‡	‡	‡	1.50 to 1.80	1.05	V

HEAT TREATMENTS

Heat Treatment A
After forging or machining:
1. Carbonize between 1600° and 1750° F. (1650°-1750° F. desired.)
2. Cool slowly or quench.
3. Reheat to 1450°-1500° F. and quench.

Heat Treatment B
After forging or machining:
1. Carbonize between 1600° F. and 1750° F. (1650°-1700° F. desired.)
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1550°-1625° F.
4. Quench.
5. Reheat to 1400°-1450° F.
6. Quench.
7. Draw in hot oil at 300° to 450° F., depending upon the degree of hardness desired.

Heat Treatment D
After forging or machining:
1. Heat to 1500°-1600° F.
2. Quench.
3. Reheat to 1450°-1500° F.
4. Quench.
5. Reheat to 000°-1200° F. and cool slowly.

Heat Treatment E
After forging or machining:
1. Heat to 1500°-1550° F.
2. Cool slowly.
3. Reheat to 1450°-1550° F.
4. Quench.
5. Reheat to 600°-1200° F. and cool slowly.

Heat Treatment F
After shaping or coiling:
1. Heat to 1425°-1475° F.
2. Quench in oil.
3. Reheat to 400°-900° F., in accordance with temper desired, and cool slowly.

Heat Treatment G
After forging or machining:
1. Carbonize between 1600° F. and 1750° F. (1650°-1700° F. desired.)
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1500°-1550° F.
4. Quench.

Heat Treatment Q
After forging:
1. Heat to 1475°-1525° F. (Hold at this temperature one-half hour, to insure thorough heating).

5. Reheat to 1300°-1400° F.
6. Quench.
7. Reheat to 250°-500° F. (In accordance with the necessities of the case) and cool slowly.

Heat Treatment H
After forging or machining:
1. Heat to 1500°-1600° F.
2. Quench.
3. Reheat to 600°-1200° F. and cool slowly.

Heat Treatment K
After forging or machining:
1. Heat to 1500°-1550° F.
2. Quench.
3. Reheat to 1300°-1400° F.
4. Quench.
5. Reheat to 600°-1200° F. and cool slowly.

Heat Treatment L
After forging or machining:
1. Carbonize between 1600° F. and 1750° F. (1650°-1700° F. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1400°-1500° F.
4. Quench.
5. Reheat to 1300°-1400° F.
6. Quench.
7. Reheat to 250°-500° F. and cool slowly.

Heat Treatment M
After forging or machining:
1. Heat to 1450°-1500° F.
2. Quench.
3. Reheat to 500°-1250° F. and cool slowly.

Heat Treatment P
After forging or machining:
1. Heat to 1450°-1500° F.
2. Quench.
3. Reheat to 1375°-1450° F.
4. Quench.
5. Reheat to 500°-1250° F. and cool slowly.

2. Cool slowly.
3. Machine.
4. Reheat to 1375°-1425° F.
5. Quench.
6. Reheat to 250°-550° F. and cool slowly.

Heat Treatment R
After forging:
1. Heat to 1500°-1550° F.
2. Quench in oil.
3. Reheat to 1200°-1300° F. (Hold at this temperature three hours.)
4. Cool slowly.
5. Machine.
6. Reheat to 1350°-1450° F.
7. Quench in oil.
8. Reheat to 250°-500° F. and cool slowly.

Heat Treatment S
After forging or machining:
1. Carbonize at a temperature between 1600° F. and 1750° F. (1650°-1700° F. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1650°-1750° F.
4. Quench.
5. Reheat to 1475°-1550° F.
6. Quench.
7. Reheat to 250°-550° F. and cool slowly.

Heat Treatment T
After forging or machining:
1. Heat to 1650°-1750° F.
2. Quench.
3. Reheat to 500°-1300° F. and cool slowly.

Heat Treatment U
After forging:
1. Heat to 1525°-1600° F. (Hold for about one-half hour.)
2. Cool slowly.
3. Machine.
4. Reheat to 1650°-1700° F.
5. Quench.
6. Reheat to 350°-550° F. and cool slowly.

Heat Treatment V
After forging or machining:
1. Heat to 1650°-1750° F.
2. Quench.
3. Reheat to 400°-1200° F. and cool slowly.

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* Another grade of this type of steel is available with chromium content of .15 per cent. to .45 per cent. It has somewhat lower physical properties.

† Two types of steel are available in this class; one with manganese .25 per cent. to .50 per cent. (.35 per cent. desired), and silicon not over .20 per cent.; the other with manganese .60 per cent. to 80 per cent. (.70 per cent. desired,) and silicon .15 per cent. to .50 per cent.

‡ Not specified and is not to be included in specification when ordering steel.

§ Steel made by the acid process may contain maximum .05 phosphorus.

|| Heat Treatment "M" is used when this steel is intended for structural parts.

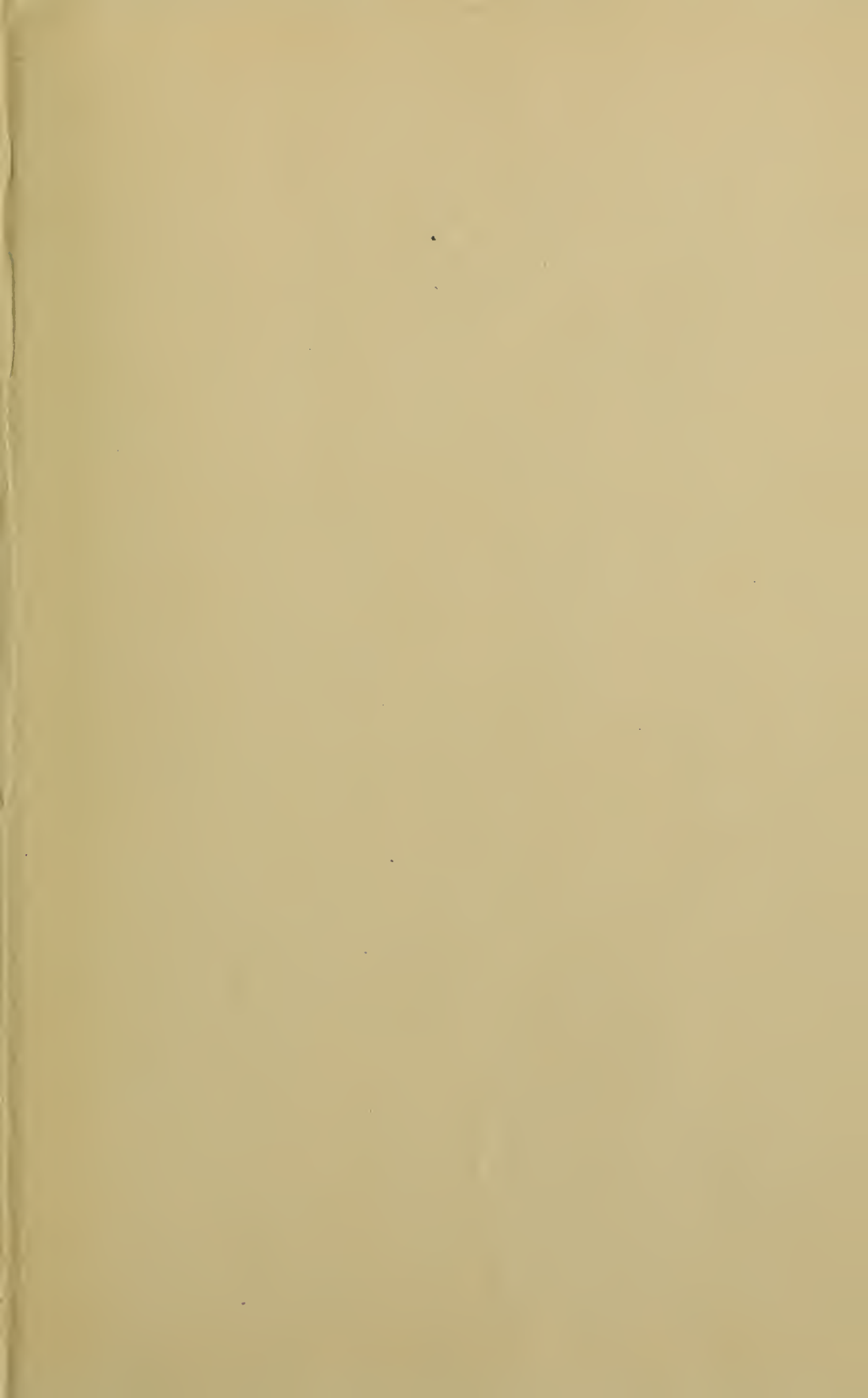¶ Heat Treatment "T" is used when this steel is intended for structural parts.